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Supplemental Modeling Scenarios

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For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600, Olympia, WA 98504-7600
Phone: (360) 407-6764

Washington State Department of Ecology - www.ecy.wa.gov

○ Headquarters, Olympia	(360) 407-6000
○ Northwest Regional Office, Bellevue	(425) 649-7000
○ Southwest Regional Office, Olympia	(360) 407-6300
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Cover photo

Red-brown algae bloom (*Ceratium fusus* and *Akashiwo sanguinea*) and organic debris, southern Budd Inlet, July 15, 2013. Photo by Marine Monitoring Unit, Department of Ecology.

Deschutes River, Capitol Lake, and Budd Inlet Total Maximum Daily Load Study

Supplemental Modeling Scenarios

by

Mindy Roberts, Greg Pelletier, and Anise Ahmed

Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

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Abstract

Portions of the Deschutes River, Capitol Lake, and Budd Inlet do not meet the water quality standards and are on the Clean Water Act Section 303(d) list of impaired waters. Previous publications summarize monitoring programs and modeling analyses conducted by the Department of Ecology and partners that identify how much human activities contribute to these impairments. This report summarizes supplemental modeling analyses conducted since the technical report that were identified and prioritized with stakeholders as potential management actions. Results were presented to and discussed with stakeholders in 2011-13.

The cumulative impact of all human activities causes dissolved oxygen concentrations to decrease by more than 0.2 mg/L throughout most of south and central Budd Inlet compared with natural conditions without human sources and without the Capitol Lake dam. The Capitol Lake dam causes the largest negative impact on dissolved oxygen of any activity evaluated due to the combined effects of changing circulation and nitrogen and carbon loads. Reducing nitrogen loads from external sources beyond Budd Inlet, LOTT outfall, and nonpoint sources would provide some oxygen benefits. Adding advanced nitrogen removal treatment to three small wastewater treatment plants in Budd Inlet, shifting the LOTT outfall north, and reducing recreational or marina boat discharges would not improve oxygen conditions significantly.

Human phosphorus contributions also cause oxygen concentrations to change in Capitol Lake by more than 0.2 mg/L. Strong nonpoint source reductions would reduce phosphorus loads. However, Capitol Lake water quality would not improve significantly because natural sources would continue to provide phosphorus from the watershed and lake sediments would continue to fuel plant growth in the lake. Reducing Deschutes River temperature, conducting alum treatments in the lake, eliminating stormwater sources, and dredging the lake to a nominal 13 ft average depth would not improve water quality in Capitol Lake significantly.

The future Water Quality Improvement Report for Budd Inlet and Capitol Lake will establish numeric load and wasteload allocations needed to meet water quality standards.

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Introduction

Portions of the Deschutes River, Capitol Lake, and Budd Inlet do not meet the water quality standards. These water bodies are on the Clean Water Action Section 303(d) list for one or more of the following parameters: fecal coliform bacteria, temperature, dissolved oxygen (DO), pH, or fine sediment. The Washington State Department of Ecology (Ecology), in cooperation with the Squaxin Island Tribe, Thurston County, City of Olympia, and others, has been conducting a Total Maximum Daily Load (TMDL) Study, also called a Water Cleanup Plan, to determine the actions needed to meet the water quality standards.

Ecology previously published the technical components of the TMDL (Roberts et al., 2012). For fecal coliform bacteria and fine sediment, the report included both current levels and reduction targets needed to meet the water quality standards based on analyses of data. Roberts et al. (2012) also recommended restoring riparian shade and improving channel conditions throughout the Deschutes River and Percival Creek watersheds to cool peak water temperatures as much as 6.9°C based on temperature modeling. Water quality improvement targets were also recommended to meet DO and pH standards in the Deschutes River and Capitol Lake. Roberts et al. (2012) quantified how much impact human activities are having on Capitol Lake and Budd Inlet DO but did not evaluate detailed scenarios needed to establish load and wasteload reduction targets.

Ecology is currently developing the Water Quality Improvement Report and Implementation Plan (WQIR/IP) for the freshwater portions of the TMDL (Wagner and Bilhimer, in development). This report will identify management actions needed to meet the fecal coliform, temperature, DO, and fine sediment water quality standards in the Deschutes River and tributaries as well as tributaries to Capitol Lake and Budd Inlet. However, the equivalent for Capitol Lake and Budd Inlet will follow in a second WQIR/IP, currently scheduled to begin in 2015.

In the interim, this report presents results from modeling scenarios conducted following the publication of the technical report (Roberts et al., 2012). The scenarios were initially identified in a brainstorming session at the September 2011 meeting of the Deschutes Advisory Group. These were refined and prioritized in the February 2012 advisory group meeting. Results were presented to the advisory group in May, July, and November 2012 and June 2013 but were not published in a report. Additional scenarios focused on the Capitol Lake influence on southern Budd Inlet were published in Ahmed et al. (2014). While Deschutes River scenarios were presented at the May 2012 advisory group meeting, they are not included in this report because they are incorporated into the freshwater WQIR/IP in development. This report focuses on scenarios related to Capitol Lake and Budd Inlet.

Previous Findings and Study Information

Roberts et al. (2012) provided detailed descriptions of the study area, water quality standards, project goals, and study objectives. The sections below highlight key aspects, but refer to the original report for additional information. Roberts et al. (2012) also describes the study methods, results, and discussions; these are summarized in later report sections.

Watershed description

The study area extends from the headwaters of the Deschutes River northward through Capitol Lake and Budd Inlet (Figure 1). The 186-mi^2 watershed includes portions of Thurston County, Lewis County, the cities of Olympia, Lacey, and Tumwater, and the town of Rainier. Land cover includes a mix of forested lands, agricultural uses, rural, residential, and urban lands.

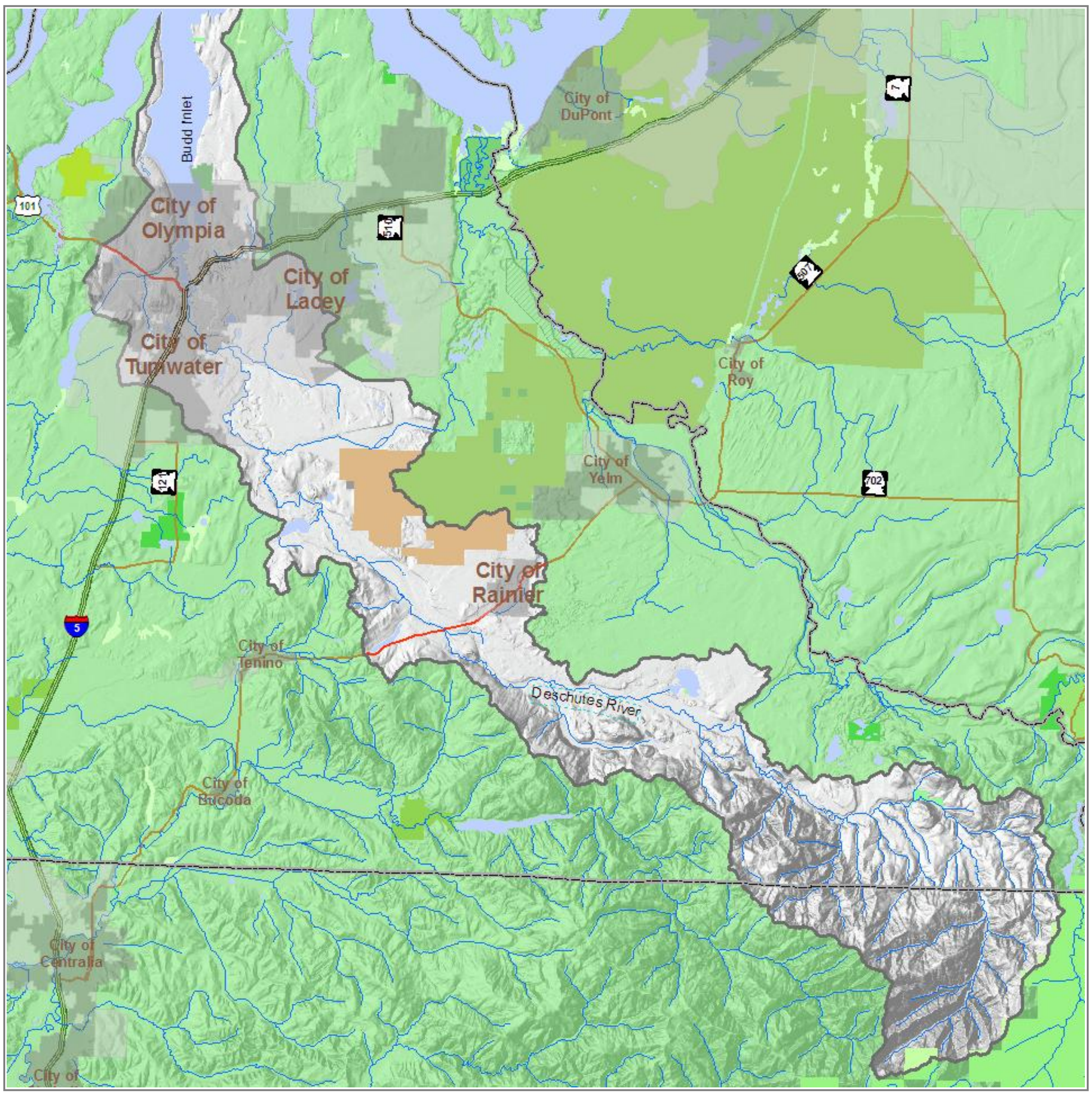


Figure 1. Deschutes River, Capitol Lake, and Budd Inlet TMDL study area.

Most of the urban lands are served by the Lacey, Olympia, Tumwater, and Thurston County (LOTT) Clean Water Alliance, which provides secondary wastewater treatment before discharging to Budd Inlet as well as advanced treatment (nitrogen removal) from April through October. Three other smaller wastewater treatment plants discharge to Budd Inlet, including Boston Harbor, Seashore Villa, and Tamoshan. Outside of the urban area, wastewater needs are served by onsite sewage systems. Ecology regulates these through National Pollutant Discharge Elimination System (NPDES) permits.

Ecology also regulates stormwater from the Washington State Department of Transportation (WSDOT), municipal Phase 2 jurisdictions, industrial, and construction facilities. Sand and gravel operations also operate under general permits. Two dairies operate within the watershed with nutrient management plans certified by the Thurston Conservation District. The Washington Department of Fish and Wildlife operates the Tumwater Falls Hatchery as a seasonal salmonid rearing facility. Commercial forestry activities are managed in accordance with Section M-2 of the Forests and Fish Report (USFWS et al., 1999). Ecology extended Clean Water Act assurances contingent upon meeting a series of corrective milestones for the forest practices operational and adaptive management programs (Hicks, 2009).

Potential pollutant sources include a variety of point and nonpoint sources (Table 1). Lack of riparian vegetation, centralized wastewater facilities, onsite sewage systems, domestic animals, fertilizers, recreational users, roads, forest practices, land clearing, dams, and natural phenomena contribute to water quality impairments.

Table 1. Potential pollutant sources in the Deschutes River, Capitol Lake, and Budd Inlet watershed.

Potential Pollutant Sources
Temperature
Lack of riparian shade
Low summer streamflows due to climate fluctuations, climate change, and anthropogenic activities
Elevated temperatures from stormwater runoff
Increases stream surface area due to natural and anthropogenic activities
Point source discharges covered under general permits for municipal stormwater, industrial stormwater, construction stormwater, and sand and gravel operations
Fecal Coliform Bacteria, Nutrients, DO, and pH
Human wastewater (centralized wastewater, onsite sewage systems, recreational users)
Domestic animals
Agricultural activities, including dairies
Wildlife
Fine Sediment
Landslides (natural and anthropogenic)
Bank erosion (natural)
Road building and road surface erosion
Timber harvest
Agricultural activities
Residential development
Stormwater runoff

Links among dissolved oxygen, nutrients, and circulation in marine and freshwater

Aquatic organisms require oxygen dissolved in the water column to live and grow. The concentration is measured as milligrams of oxygen per liter of water, or mg/L. One mg/L is equivalent to one part per million, so DO concentrations are quite low. Without sufficient oxygen, aquatic life become stressed and can die if levels are too low.

DO levels in marine and freshwater environments result from complex interactions of physical, chemical, and biological processes. These include water circulation that dictates how long a parcel of water stays in one location, the solubility of oxygen in water defined by temperature, salinity and pressure, living aquatic plants that use and produce oxygen, dead organic matter that settles to the bottom, and decomposition of organic matter. All must be considered to understand what factors influence DO levels.

Aquatic plants grow in marine and freshwater environments in the presence of light and the nutrients nitrogen and phosphorus. Algae, or phytoplankton, are plants suspended in the water. Rooted plants, or macrophytes, can also grow in these environments. During the day, these plants take in CO2 and produce oxygen as a waste product. At night, in deep water where light is attenuated, or where other factors shade them, plants use oxygen and produce CO2. As the plants die and decay, their decomposition uses up oxygen in the process.

Plants require both nitrogen and phosphorus to grow, but in different amounts. The ratio of nitrogen to phosphorus in plant materials varies among species. When nitrogen and phosphorus concentrations are represented as mg/L, aquatic plants are typically made up of about 7.2 parts nitrogen to 1 part phosphorus. In other words, for every mg of P in plant material there would be about 7.2 mg of N. In lake environments, the ratio in the water is usually greater than 7.2, indicating that plant growth is generally limited by phosphorus. In marine environments, the ratio in water is usually less than 7.2, indicating that plant growth is generally limited by nitrogen. Different algae species grow in freshwater and marine water environments.

Nitrogen and phosphorus exist in several forms (Figure __). Nitrogen and phosphorus include both dissolved and particulate forms. These also have organic and inorganic forms. In general, plants convert dissolved inorganic nitrogen and inorganic phosphorus into particulate organic forms. Waste products may also involve dissolved organic nitrogen and dissolved organic phosphorus. Dissolved inorganic nitrogen includes three forms. Nitrate and ammonium are most prevalent. Nitrite is sometimes present, but only in very small amounts. Dissolved inorganic phosphorus is generally described as orthophosphate or soluble reactive phosphorus. Lab measurements are needed to distinguish which forms of nitrogen or phosphorus are present in water samples.

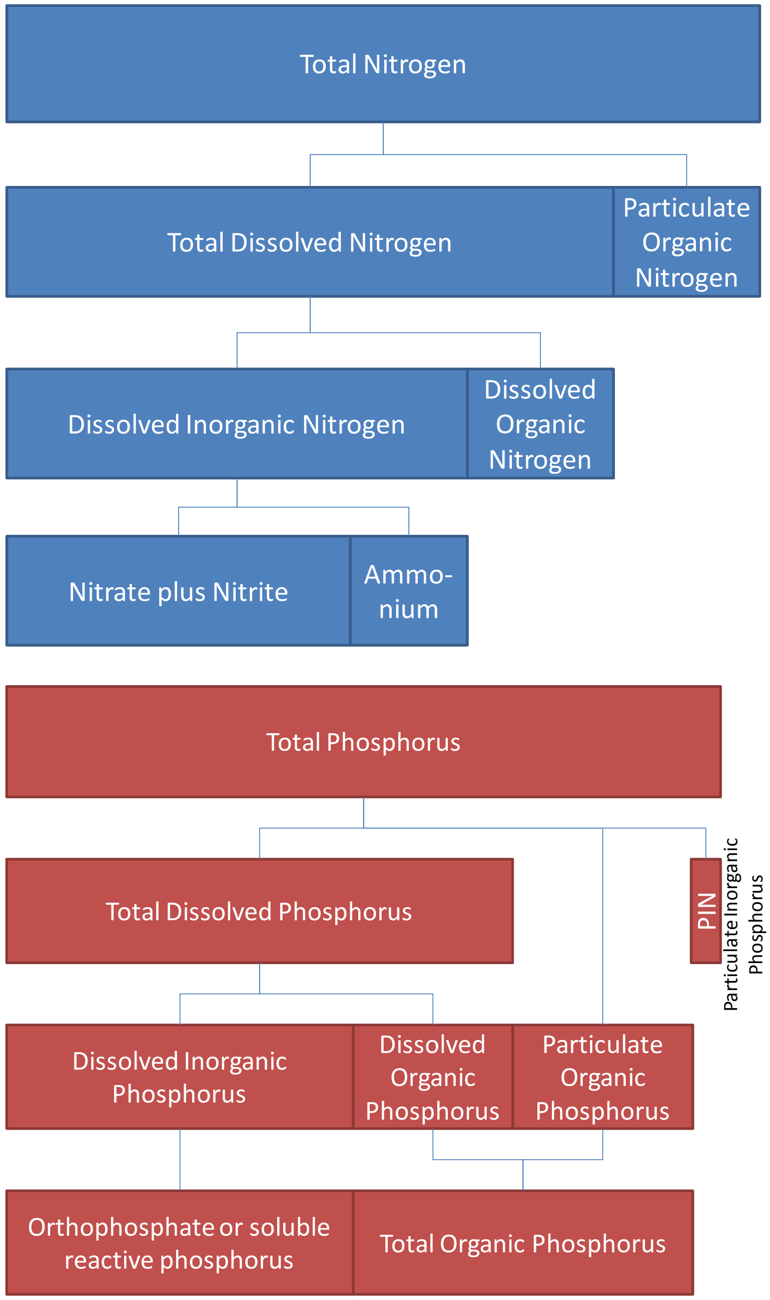


Figure 2. Forms of nitrogen and phosphorus

Physical processes like circulation also influence the amount of algae growth. Where water flushes quickly, suspended plants cannot propagate faster than they are flushed out of a region, and lower algae concentrations exist. In regions that are poorly flushed and water stagnates, algae can increase and form blooms. Blooms can deplete the nutrients available for growth if the resupply of these nutrients is limited. Nutrient inputs can come from the surrounding lands or from lower down in the water column where little light is available to drive photosynthesis. One example of changing land inputs is river flow rates that vary by season. In both marine and freshwater environments, the water can be very stratified. These density gradients restrict the vertical exchange of water and nutrients from lower in the water column into the upper water column. The surface layer where light is available for plant growth is called the euphotic zone. The surface layer can also be defined by temperature, called the thermocline, or chemical factors, called the pycnocline.

In marine waters, the tides, marine water intrusions, and freshwater inputs influence circulation, algae growth, and oxygen levels, in addition to vertical mixing. Tidal circulation varies with the phase of the moon. The range of the tide (difference between high and low tides) varies over a two-week cycle. About twice a month around the time of a new moon or a full moon, the tide's range is at its maximum and called a spring tide. During spring tides, the largest amount of water moves back and forth. When the moon as at the first and third quarter the tide's range is at its minimum and called a neap tide. During neap tides, less water moves back and forth. The spring-neap cycle affects the residence time of water, which in turns influences the oxygen levels.

In addition, marine water intrusions and freshwater inputs to marine waters drive estuarine circulation. Freshwater has a lower density and floats on top of the denser marine water. Ocean upwelling brings in cooler water with higher salinity that is denser than other marine waters and rides along the bottom of Puget Sound. On each flooding tide, the marine intrusions travel more landward at the bottom. On the ebbing tide the freshwater travels more toward the ocean at the surface. This produces a conveyor belt that strongly influences how long water remains in different marine areas.

The water volume and rates of inflow and outflow influence circulation in lakes, which don't experience tides. As the lake volume decreases relative to the inflows, the residence times decreases. Alternatively, if the water inflows are large, the residence time decreases. Thermal stratification of lakes during summer occurs because the surface layer is heated by atmospheric heat inputs. When a lake stratifies, the mixing of water from top to bottom is reduced. During stratification, the bottom layer may become depleted in oxygen because it is blocked from reaeration by the atmosphere. The bottom layer may also build up higher concentrations of nutrients due to settling and sediment flux. Wind events during summer may completely mix the water column from top to bottom in a shallow lake like Capitol Lake and transport enriched nutrients from the bottom into the surface layer.

Chemical factors also influence the amount of oxygen in marine or freshwater. The solubility of oxygen is higher at cooler temperatures, meaning that cold water holds more oxygen than warm water does. This holds for both marine water and freshwater. In marine water, DO solubility is also influenced by salinity. Solubility decreases with increasing salinity. High-salinity marine water holds less oxygen than low-salinity marine water. Finally, saturation is also influenced by altitude due to the relationship with atmospheric pressure.

Once plants die, they settle toward the bottom as particles. The sediments are active zones of transformation, driven by this particle rain. At the surface of the sediments, biological processes use up oxygen in the overlying waters and release nutrients back to the water column where it can fuel additional plant growth. These processes exist in both marine and lake systems, although the key nutrient varies. In marine waters, the release of nitrogen in the form of ammonium can fuel plant growth. In lakes, the release of inorganic phosphorus fuels plant growth. Many factors influence how much oxygen, nitrogen, and phosphorus are released back to the water column, including oxygen and pH of the overlying water, temperature, microbial community, and deep sediment burial rates.

Nutrients from the land reach marine water and freshwater through several pathways. Precipitation falling on forests and other natural vegetation areas sinks into the soil but some of it runs off into streams and river, which can carry natural sources of nutrients to lakes and marine waters. Precipitation also falls on lands with human activities, including residential, agricultural, and commercial land cover. Less of the water sinks into the soil and more of it runs off, carrying with it some natural nutrients but also nutrients from human activities.

The processes that influence DO vary with time. For example, ocean upwelling and broader precipitation patterns vary from year to year. Many processes vary seasonally within the year, driven by summer/winter cycles of light availability and ambient temperature. These in turn affect physical processes such as the depth of the euphotic zone in marine water or lakes, as well as biological processes such as plant growth. Algae blooms follow a strong seasonal cycle but also vary on time scales of days to weeks. River inflow varies strongly by season, with highest inflows in the late fall and winter and seasonal minimum flows in the late summer. Processes that vary daily or weekly include storm patterns and spring/neap cycles in marine waters, which strongly influence biogeochemical processes. Over the course of the day, the day/night cycle influences temperature as well as biological processes.

Water Quality Standards for dissolved oxygen

Water quality standards define the goals for a water body by designating beneficial uses, setting criteria to protect those uses, and establishing provisions to protect water bodies from pollutants. The beneficial uses to be protected by this TMDL are recreation, aquatic life, water supply, and miscellaneous (wildlife habitat, harvesting, commerce/navigation, boating, and aesthetics). The water quality standards include numeric criteria for different parameters that vary by designated use. The water quality standards also protect waters of higher quality than the numeric criteria, and the antidegradation process prevents unnecessary lowering of water quality.

Water quality standards are established by Washington State to protect the designated uses. WAC 173-201A-612 lists use designations for marine water bodies. Lakes are defined in WAC-173-201A-600(1). The health of fish and other aquatic species depends upon maintaining an adequate supply of DO. Growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants are all affected by oxygen levels in both lake and marine environments. The state's criteria are designed to maintain conditions that support healthy populations of fish and other aquatic life.

Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiratory requirements of aquatic plants and algae. Concentrations tend to be higher near the water surface and lower near the sediments. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criteria is expressed as the lowest 1-day minimum oxygen concentration that occurs anywhere in a water body and is not applied as a water-column average or daily average.

Marine waters

Budd Inlet south of Priest Point Park is designated Good Quality Aquatic Life, while the rest of Budd Inlet is Excellent Quality Aquatic Life. The area south of the Capitol Lake dam would be subject to the Good Quality Aquatic Life criteria without the dam in place.

The marine DO standard has two parts. First, the standards establish minimum criteria that vary with designated use (Figure __):

(1) To protect the Excellent quality category of aquatic life use, the lowest 1-day minimum oxygen level must not fall below 6.0 mg/L more than once every 10 years on average.

(2) To protect the designated Good Quality category of aquatic life use, the lowest 1-day minimum oxygen level must not fall below 5.0 mg/L more than once every 10 years on average.

The criteria are used to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. The second part of the standard states that when marine waters are naturally lower than the oxygen criteria, an additional allowance is provide for further depression of oxygen conditions due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.2 mg/L decrease below that naturally lower (inferior) oxygen condition.

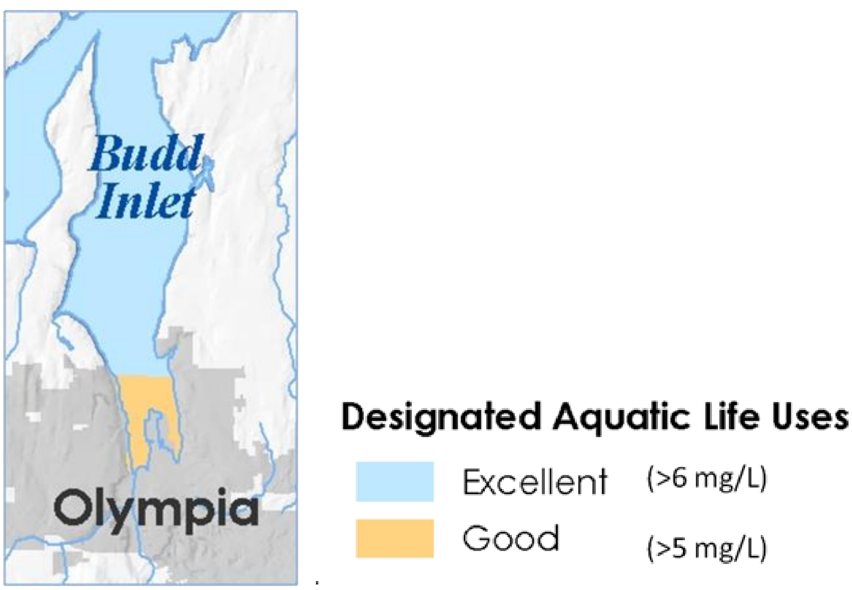


Figure 3. Water quality standards in Budd Inlet and Capitol Lake.

Capitol Lake

Capitol Lake with the dam in place is designated as Lake Class (Appendix B of Roberts et al., 2004). The DO standard for lakes is that human actions considered cumulatively may not change the 1-day minimum oxygen concentration more than 0.2 mg/L from natural conditions.

Project goals and study objectives

The overall project goals are to determine the loading capacity for fecal coliform bacteria, temperature, DO, nutrients, pH, and fine sediment in the Deschutes River, Capitol Lake, Budd Inlet, and their tributaries. Roberts et al. (2012) defines overall study objectives for fecal coliform bacteria, temperature, DO, nutrients, pH, and fine sediment. The objective of this report is to present supplemental modeling results on DO for Capitol Lake and Budd Inlet in advance of the subsequent WQIR/IP scheduled to begin in 2015.

Report Organization

This report supplements the information presented in Roberts et al. (2012) based on subsequent modeling and analyses. We summarize the Methods used to develop and analyze the scenarios. We cite Roberts et al. (2012) for details and summarize pertinent information to provide sufficient context for interpreting the supplemental results. The Results and Discussion section describes model output and analyses performed based on recommendations and priorities of the Deschutes Advisory Group. The Conclusions section summarizes the major findings and the implications, while the Recommendations section identifies potential next steps.

Methods

Roberts et al. (2012) describes the data collection and modeling activities conducted to assess pollutant sources and impacts in the overall study area. This section summarizes the methods used to develop the supplemental model scenarios for Budd Inlet and Capitol Lake. Refer to the original report for details related to data collection, quality assurance, model development, and model calibration.

Model Overview

J.E. Edinger Associates, Inc. (JEEAI) applied the three-dimensional hydrodynamic and water quality model GLLVHT (Generalized, Longitudinal-Lateral-Vertical Hydrodynamics and Transport model) in the Budd Inlet Scientific Study (BISS) conducted from 1996-1998 (Aura Nova Consultants et al., 1998), with follow-up work in 1999 and 2000 (Aura Nova Consultants and J.E. Edinger Associates, 1999). JEEAI was subsequently acquired by ERM Group Inc. (ERM). The GLLVHT modeling framework was updated by JEEAI and ERM and is currently called the Generalized Environmental Modeling System for Surfacewaters (GEMSS).

The original JEEAI model application was performed for Lacey, Olympia, Tumwater and Thurston County (LOTT) Wastewater Partnership (name since changed to LOTT Clean Water Alliance) to support National Pollutant Discharge and Elimination System (NPDES) permitting activities (Aura Nova et al., 1999). The model consisted of hydrodynamic and carbon-based water quality computations and was calibrated for the 1997 field data.

Ecology applied the Generalized Environmental Modeling System for Surface Waters (GEMSS) to simulate current and potential water quality in Budd Inlet and Capitol Lake. GEMSS is an integrated system of three dimensional (3-D) hydrodynamic and transport models embedded in a geographic information and environmental data system (GIS) and set of pre- and post-processing tools to support 3-D modeling. The theoretical basis of the three dimensional model was first presented in Edinger and Buchak (1980) and subsequently in Edinger and Buchak (1985) under the previous name called GLLVHT for the Generalized Longitudinal, Lateral, and Vertical Hydrodynamic Transport model.

GEMSS has been peer reviewed and published (Edinger and Buchak, 1995; Edinger, et al., 1994 and 1997). The fundamental computations are an extension of the well known longitudinal-vertical transport model that was developed by J.E. Edinger Associates, Inc. beginning in 1974 and summarized in Buchak and Edinger (1984). This model forms the hydrodynamic and transport basis of the Corps of Engineers' water quality model CE-QUAL-W2 (U.S. Army Engineer Waterways Experiment Station, 1986). GEMSS has previously been applied in Budd Inlet (Roberts et al., 2012) and many other waterbodies (e.g., Fischera et al., 2005).

The circulation model simulates water surface elevations, velocity, temperature, and salinity throughout the model domain. The hydrodynamic module and three water quality modules of GEMSS were used to simulate hydrodynamics and water quality variables in Budd Inlet and Capitol Lake in this study:

- Transport module was used to simulate hydrodynamic variables including water levels, current velocities, temperature, and salinity.
- WQCBM module was used to simulate one saltwater phytoplankton group in Budd Inlet (dinoflagellates), dissolved oxygen (DO), ammonia, nitrate, inorganic P, dissolved organic N, particulate organic N, dissolved organic P, particulate organic P, and dissolved organic C (CBOD).
- GAM module was used to simulate two additional saltwater phytoplankton groups in Budd Inlet and two freshwater phytoplankton groups in Capitol Lake. The influence of the GAM phytoplankton groups on variables in the WQCBM module was accounted for in the WQCBM module.
- WQADD module was used to simulate the combined bottom plant community of macrophytes, epiphytes, and attached algae in Capitol Lake as a lumped variable that is referred to hereafter as macrophytes. The influence of macrophytes on variables in the WQCBM module was accounted for in the WQCBM module.

The transformation of nutrient forms of carbon, nitrogen, and phosphorus, and the influence on DO within Capitol Lake by macrophytes and phytoplankton were simulated. The mass transfer of transformed nutrient forms between Capitol Lake and Budd Inlet also was simulated, including accounting for the oxygen demand and organic carbon, nitrogen, and phosphorus in the biomass of freshwater phytoplankton subject to salinity-induced die-off in Budd Inlet.

The key water quality constituents include the various forms of carbon, nitrogen, and phosphorus (dissolved organic carbon, particulate organic carbon, nitrate, ammonia, organic nitrogen, inorganic phosphorus, and organic phosphorus), as well as phytoplankton biomass (chlorophyll-a), macrophyte biomass, DO, temperature, and sediment fluxes of oxygen, nitrate, ammonia, and inorganic phosphorus.

Parameter Estimation and Final Calibration

The process of calibrating a water quality model involves selection of values for parameters that represent various kinetic processes. Calibration of the model for this project involved running batches of typically about 100 model runs at a time with a matrix of critical parameter estimates varying around a base model run that had the best skill from the previous batch (Roberts et al., 2012). The parameter estimates were constrained to be within the ranges of prior distributions of expected reasonable values. The results of each batch of runs were examined to compare the relative model skill with different combinations of parameter values. Information about which combinations of parameters improved the model skill was used to guide the selection of parameter values for the base model run of the next batch and for the development of new parameter combinations for sensitivity analysis in the batch.

Two approaches were used to assess model skill for each batch during the parameter estimation process and to guide the selection of the base parameter set for the next batch of runs for sensitivity analysis:

- Graphical comparison of predicted and observed values using charts of time series and profiles of concentrations;

- Ranking of model runs based on a weighted average root mean squared error (RMSE) statistic that combined the skill for prediction of bottom DO, entire water column DO, DIN, and chlorophyll a to describe the overall goodness-of-fit.

The entire process of parameter optimization – including the selected base parameter values in each batch and the matrix of parameter variations that were used for sensitivity analysis in each batch, as well as the corresponding charts of model output comparing predicted and observed conditions and goodness-of-fit statistics for all 1500 model runs – is documented in a Web-based model output browser (https://fortress.wa.gov/ecy/spsdos/bicl/index.html).

The final model calibration was applied in Roberts et al. (2012) to determine the impacts of local point and watershed sources on minimum DO in Budd Inlet.

Independent Peer Review

During the development of the technical study, Ecology requested two paid independent peer reviews of the Budd Inlet and Capitol Lake modeling. EPA Region 10 worked with its national consultant pool twice. The first review was conducted by Cadmus Group and Dr. Scott Wells of Portland State University. The scope of work included model setup and development, model calibration, scenario analyses, and documentation. The draft review in February 2009 (Cadmus Group and Wells, 2009) led to further model development and calibration, which was incorporated into a subsequent external review draft. In December 2011, Dr. Wells confirmed the report and response to comments addressed all comments to the satisfaction of the reviewer (Wells and Berger 2011).

The independent review triggered a model code change. To ensure this was also reviewed, Ecology requested a second paid independent review through EPA. EPA contracted Cadmus through its national consultant pool, and Cadmus hired Jim Fitzpatrick of HDR-HydroQual to perform the second review of the model. This was related to phytoplankton kinetics. The code was reviewed and comments addressed to the satisfaction of the subsequent independent reviewer (Blake, 2012).

Budd Inlet Modeling

Calibration of the GEMSS model of Budd Inlet is presented in Roberts et al (2012). The model grid originally developed for the Budd Inlet Scientific Study (BISS) was used for calibration of the GEMSS model for the present project (Figure x). This original BISS grid used for calibration of Budd Inlet did not include Capitol Lake. The outflow from Capitol Lake was input to the model as a boundary condition at the dam using the same method as the original BISS study. All of the boundary conditions for the model for calibration were from the 1997 dataset from the BISS (e.g., Capitol Lake outflow and loads, point sources loads, sediment/water fluxes, meteorology, etc.). The simulation period is January 25 through September 15, 1997.

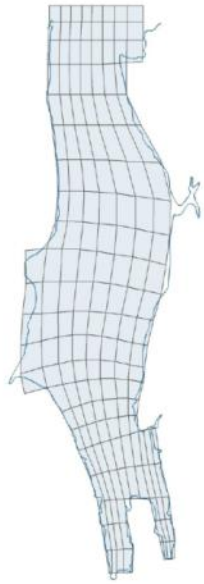


Figure 4. GEMSS model grid used for calibration of the Budd Inlet model.

Budd Inlet scenarios

The Deschutes Advisory Group (DAG) convened on September 22, 2011 and proposed a list of potential alternative management scenarios that were considered to be worthwhile to provide information for prioritizing management decisions. Ecology re-organized the list of scenarios and proposed that selected scenarios would be the highest priority for evaluation using the modeling tools that were developed during the TMDL project. Appendix A presents the re-organized list of scenarios that was subsequently discussed by the DAG in February 2012.

The re-organized list included nine scenarios to supplement the scenarios presented in Roberts et al. (2012). The additional nine scenarios include six scenarios mostly related to Budd Inlet and three scenarios related to Capitol Lake.

The additional scenarios related to Budd Inlet were set up for modeling as follows:

- **Reduce nonpoint nitrogen loading.** No local data are available on the effectiveness of specific BMPs other than large centralized, publicly owned facilities. Nutrient benefits generally are recognized but not quantified. The modeling approach was to decrease the input of nonpoint source nitrogen by 10, 20, and 50% to bound nutrient target reductions.
- **Advanced wastewater treatment for all point sources discharging to Budd Inlet.** LOTT generally achieves 2 mg/L dissolved inorganic nitrogen (DIN) in summer. Biological nutrient removal technology can decrease effluent concentrations to 6 to 10 mg/L. However, advanced treatment is required to achieve lower concentrations in the summer months. The modeling approach was to set all WWTP discharges to 3 mg/L for April-September period while no changes were made during rest of the year. LOTT remained at current treatment practices.

- **Extend LOTT outfall.** The modeling approach was to evaluate with GEMSS model moving the LOTT discharge location to a different grid cell.
- **Reduce N loading from sources external to Budd Inlet (e.g., South and Central Puget Sound sources).** The modeling approach was to evaluate with the GEMSS model of South and Central Puget Sound to estimate the amount of change in the open boundary of the GEMSS model of Budd Inlet corresponding to a change in the anthropogenic load to South and Central Puget Sound.
- **Shellfish for restoration.** The approach was to compare the potential nitrogen mass removed to human nutrient contributions.
- **Decrease boater waste (recreational boaters on Budd Inlet and marinas).** The approach was to compare the potential nitrogen mass added to other human contributions.

Natural conditions for Budd Inlet

Roberts et al. (2012) showed that the operation of the dam for Capitol Lake causes widespread depletion of bottom DO throughout inner Budd Inlet during July-September of greater than 1 mg/L, and greater than 2 mg/L in East Bay. At the time of the 2012 report, the DO depletion caused by the dam was not considered to be part of the potential for violating the water quality standard. The effects of human anthropogenic loads were compared with two base scenarios with only natural nitrogen sources and no human loads: (1) with the dam in place and (2) without the dam in place. Without the dam in place, the area covered by Capitol Lake would become an estuary and subject to marine DO standards.

Following the 2012 study Ecology consulted with the office of the state Attorney General to discuss appropriate assumptions for natural background conditions for lake and estuary scenarios. The result of these internal discussions was a decision to assume that natural conditions for estuary and lake scenarios would be the same hypothetical scenario of naturally occurring loads without the dam instead of using two separate baseline conditions. The result of this change is to consider the DO depletion caused by operation of the dam to be a part of the total estimated anthropogenic DO depletion with respect to the water quality standards.

Natural conditions for Budd Inlet included changing model inputs and boundary conditions as follows compared with existing conditions:

- The dam at the outlet of Capitol Lake was removed from the model. In place of the dam, a channel with width of approximately 230 meters was assumed.
- Concentrations of water quality variables in the Deschutes River and other streams was set to estimated natural conditions as described by Roberts et al. (2012)
- Concentrations of water quality variables in the wastewater treatment plant effluents were set to estimated natural conditions of the rivers and streams as described by Roberts et al. (2012).

Sediment and water column scalars

Evaluation of scenarios other than the existing conditions required changing the model inputs to match the hypothetical conditions for each scenario. For example, the natural condition scenario required changing the model inputs for loading from the rivers to lower concentrations of nutrients. In addition to model inputs of loading from rivers, the concentrations at the open boundary, and the fluxes between the sediment and water were expected to be different under natural conditions. The open boundary concentrations and the sediment/water fluxes were adjusted by scalar multipliers to reflect the proportional change that was expected relative to the existing condition. Under natural conditions, sediment fluxes within the Capitol Lake estuary were assumed to be the same natural sediment fluxes as in the Inner Budd Inlet. Appendix A describes the development of water column and sediment scalars for the scenarios. The appendix includes a discussion of how reflux of nutrients was addressed.

Capitol Lake Modeling

The calibration period evaluated in Roberts et al. (2012) was May 18 to September 30, 2004, based on the availability of boundary condition and calibration data. Data collected by the Department of Ecology during 2004 included water column conditions within the lake, tributary loads, sediment/water fluxes, and macrophytes concentrations.

As described above, the original grid of Budd Inlet from the 1990s BISS did not include Capitol Lake. The model grid was extended for the 2012 study to include Capitol Lake and its boundary condition inputs of the Deschutes River and Percival Creek (Figure xx).

Discharge from Capitol Lake is controlled by the lake's outlet dam. Dam operations are dynamic and the tide gates opened and closed in response to tides to maintain the lake at a desired level (the "set point"). For periods with low tides when the dam gates are open, Capitol Lake discharges to Budd Inlet as if it were a major river. With the gates closed at high tides, no freshwater flow is discharged. The hydraulics of the dam also include a deep siphon below the dam and a fish weir that can flow either direction. Water exchange through either path varies with the relative water levels on either side of the dam. Flows from the dam are calculated in GEMSS using a numerical model subroutine (Aura Nova Consultants et al., 1998). Inputs to the model include Budd Inlet tides, Deschutes River and Percival Creek flows, dam set points, and temperature and salinity measurements from the lake and the inlet.

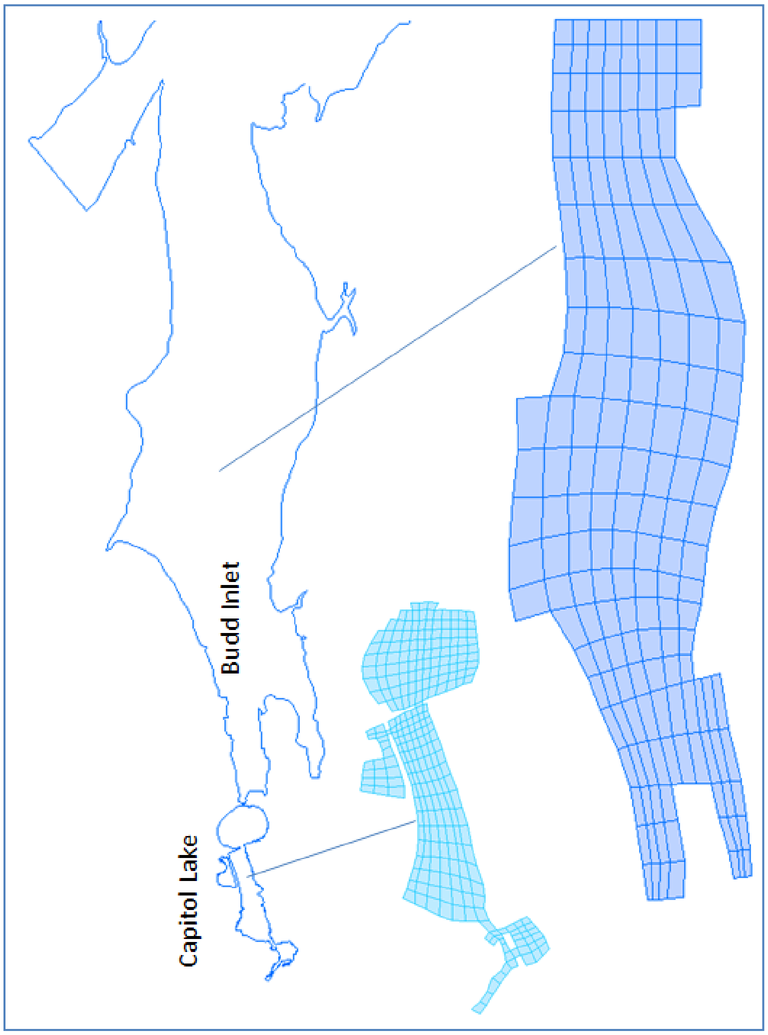


Figure 5. GEMSS model grid of Budd Inlet and Capitol Lake.

While not anticipated in the original study design (Roberts et al., 2004), during this period, herbicide was introduced into Capitol Lake to control invasive milfoil, the dominant macrophyte (see Appendix C of Roberts et al. [2012] for pre- and post application plant biomass). The sudden die-off of the invasive milfoil released nutrients into the lake that contributed to excessive algal growth.

The application of herbicide was carried out in two steps. Herbicide was first introduced in the middle and south basin on July 19, 2004, and then in the north basin on July 29, 2004, during which the outlet from the lake remained closed. To replicate this behavior, two sets of kinetic rates were adopted. One set represented the pre-herbicide period, and the second set represented the post-herbicide period.

During the calibration process, the lake was divided into four distinct basins for the purpose of considering regional specification of model parameters:

- North Basin (NB) is at the outlet of the lake and is deeper compared to other sections of the lake.

- Middle Basin (MB) is wide and shallow.
- South Basin (SB) is at the mouth of the Deschutes River.
- Percival Cove (PC) is at the mouth of Percival Creek.

Macrophyte measurements in July 2004 showed that no invasive milfoil were present in Percival Cove in the pre-herbicide period. Time-varying die-off rates were used in NB, MB, and SB to simulate die-off of invasive macrophytes during herbicide application. Macrophyte measurements in September 2004 showed populations of macrophyte at pre-herbicide levels, and no milfoil were present.

Two freshwater phytoplankton variables were simulated using the GAM module with growth kinetics varying over the four regions (NB, MB, SB, and PC) to depict the seasonal and spatial chlorophyll variation observed in the lake.

Capitol Lake scenarios

- As described above, the Deschutes Advisory Group (DAG) identified a list of potential alternative management scenarios: **Reduce nonpoint P loading to Capitol Lake.** The technical approach was to decrease the nonpoint source phosphorus contribution by 10, 20, and 50% to bound nutrient target reductions.
- **Riparian plantings.** The QUAL2KW model of the Deschutes River quantified temperature, DO, and pH benefits in technical report for the Deschutes River and found that anthropogenic sources increase the temperature about 4°C above natural conditions. The technical approach was to compare lake temperature and DO by decreasing boundary condition temperature by 4°C in the Deschutes River.
- **In-lake treatments to inactivate P.** The technical approach was to reduce the benthic flux of P from sediment to the water using the GEMSS model and find the corresponding change in DO.

Natural conditions for Capitol Lake

The natural conditions for Capitol Lake were represented by the natural watershed loads from the Deschutes River and Percival Creek. Appendix I of Roberts et al. (2012) described natural watershed conditions. In addition, sediment flux scalars were adjusted for natural conditions in Capitol Lake as described below.

Sediment scalars

The scalars for adjustment of sediment fluxes in Capitol Lake were estimated by assuming that sediment/water fluxes of oxygen (SOD) and phosphorus were proportional to the ratio of natural vs. existing total phosphorus loading from the Deschutes River and Percival Creel. Scalars for adjusting sediment/water fluxes of ammonium and nitrate plus nitrite were based on proportionality of natural/existing total nitrogen loads from the Deschutes River and Percival Creek

Scenario Comparisons with Natural Conditions or Current Conditions

DO differences for each scenario relative to natural conditions were compared for each grid cell in each layer. The water quality standards establish both an absolute numeric threshold criterion and a relative difference criterion when the natural DO level is below the numeric criterion. Budd Inlet results were compared two ways:

1. Where natural DO levels are higher than the numeric criterion, additional pollutant loading cannot cause DO levels to fall below the numeric criterion at any time.
2. Where natural DO levels are below the numeric criterion, additional pollutant loading cannot depress DO levels more than 0.2 mg/L below natural conditions at any time.

The absolute DO criteria are different for inner and outer Budd Inlet (5.0 and 6.0 mg/L, respectively, Figure 3).

For Capitol Lake, water quality standards are based on a maximum of 0.2 mg/L DO change from natural conditions, regardless of the magnitude of the DO under natural conditions.

Comparison of the water quality standards to model predictions in tidal waterbodies requires additional interpretation. The following method was used to determine whether the predicted depletion of DO for each scenario relative to natural conditions indicated a violation of the water quality standard:

- For each cell and each layer in the model, calculate the minimum DO for each day from the model output. Compare the minimum DO for each day between the natural condition and the comparison scenario.
- If the difference of any of the daily minimums any time of the year (when the natural condition daily minimum is below the absolute criterion) is greater than 0.2 mg/L, or if the comparison scenario causes the predicted DO to fall below the criterion threshold when the natural condition is above the threshold, it is a violation of the water quality standards.

Model Skill

The ability of the model to predict the observed data, also called model skill, was evaluated using two statistical measurements: the square root of the average of the squared differences between predicted and observed values, also called the root mean squared error (RMSE), and the average of the differences between the predicted and observed values (mean bias). The results of model skill measurements are presented in Roberts et al. (2012).

The model calibration process improved numeric measures of model skill, The model is considered to be suitable for the main purpose of this project to predict the response of critical bottom DO concentrations in inner Budd Inlet to variations in nutrient loading and concentration.

The typical model skill is represented by the overall RMSE of bottom layer DO reported by Roberts et al (2012) is 1.3 mg/L. The worst model skill, represented by the highest RMSE at any single station, is 2.4 mg/L at East Bay.

The mean bias at all stations is much lower than the RMSE (Roberts et al. 2012), which indicates that the model is not significantly biased overall. Roberts et al. (2012) reported that the model has a slight but insignificant tendency to over-predict the bottom DO in West Bay and under-predict the bottom DO in East Bay. The RMSE is comparable to similar model calibration studies in South Puget Sound.

In this report we use the model to calculate differences in DO between various anthropogenic loading scenarios compared with the natural condition to determine whether the predicted differences exceeded the water quality standard. Because the predicted DO in the various scenarios are highly correlated (R=0.997 for estuary existing loads vs estuary natural conditions scenarios, R=0.95 for lake existing loads vs estuary natural conditions scenarios), the RMSE of the difference between model scenarios ($RMSE_{diff}$) is much less than the RMSE of either the existing or natural condition.

The following equations estimate the variance (R^2) and RMSE of the difference between model scenario results (Var_{diff} and $RMSE_{diff}$) from the variance of the existing and natural conditions ($Var_{existing}$=$RMSE_{existing}$ ^2, $Var_{natural}$ = $RMSE_{natural}$ ^2):

$Var_{diff} = Var_{existing} + Var_{natural} - 2 * R * RMSE_{existing} * RMSE_{natural}$
$RMSE_{diff} = Var_{diff} \wedge 0.5$

For example, the following estimates of $RMSE_{diff}$ apply to the differences in DO between anthropogenic loading scenarios and natural conditions (assuming overall RMSE = $RMSE_{existing}$ = $RMSE_{natural}$ = 1.3 mg/L, RMSE at East Bay = 2.4 mg/L, R = 0.997 comparing estuary with anthropogenic loads vs estuary natural scenario, and R = 0.95 comparing lake with antrhopogenic loads vs estuary natural scenario):

- $RMSE_{diff}$ = 0.10 mg/L for overall skill comparing estuary anthropogenic loading scenarios with estuary natural conditions
- $RMSE_{diff}$ = 0.19 mg/L for East Bay comparing estuary anthropogenic loading scenarios with estuary natural conditions
- $RMSE_{diff}$ = 0.41 mg/L for overall skill comparing lake anthropogenic loading scenarios with estuary natural conditions
- $RMSE_{diff}$ = 0.76 mg/L for East Bay comparing lake anthropogenic loading scenarios with estuary natural conditions.

The estimated uncertainty of the differences ($RMSE_{diff}$) provides a measure of whether predicted differences are statistically significant. Statisticians commonly use 95% confidence as a level of probability that indicates a statistically significant difference. For example, if the predicted depletion of DO in East Bay under a scenario of anthropogenic influence under estuary management is 0.6 mg/L, then an approximate 95% confidence interval of the possible depletion in East Bay for that scenario could be estimated as plus or minus twice the $RMSE_{diff}$, of 0.19

mg/L, or a range of about 0.22 to 0.98 mg/L. Therefore, the predicted difference could be statistically significant because there would be about 95% confidence that the depletion is greater than zero or no depletion.

Results and Discussion

The calibrated model was used to evaluate the potential for violation of the DO standard. We used the model to calculate differences in DO between various anthropogenic loading scenarios compared with the natural condition to determine whether the predicted differences met or violated the water quality standard.

The first step was the creation of a scenario to represent the natural conditions and the resulting DO concentration throughout the various layers and model grid cells used to represent Budd Inlet. These were post-processed to identify the minimum daily DO concentration anywhere in the water column for the simulation period. Then several other scenarios of various amounts and kinds of anthropogenic influence were created and the DO concentrations of each scenario were compared with DO in the natural conditions scenario. Table 2 and Table 3 present the list of scenarios that were evaluated for Budd Inlet and Capitol Lake, respectively.

Table 2. Supplemental Budd Inlet management scenarios evaluated with calibrated models

Scenario	Description
Natural	WWTP = 0 Rivers = natural Sediment fluxes = natural Open boundary water quality = natural Capitol Lake dam = absent
Current Conditions	Point Source (PS or all the WWTP) = existing Non-point source (NP or all the Rivers)= existing Open boundary water quality = existing Capitol Lake dam = present
Impact of Capitol Lake dam	natural condition with and without Capitol Lake dam
Impact of local and external human sources	Current Conditions without dam
Impact of external human sources	Natural condition with current external anthropogenic N at open boundary
Impact of reducing local non-point sources	Current conditions without dam with 10%, 20%, 50% and 100% reductions in watershed (river) human nitrogen sources. The 100% NP reduction scenario reflects the impact of point sources and external anthropogenic sources
Impact of advanced treatment at three smaller plants	Difference in predicted DO under existing conditions with advanced nitrogen removal at Boston Harbor, Tamoshan, and Beverly Beach WWTPs (DIN = 3 mg/L DIN split between NH3 and NO3 based on NO3 to DIN ratio) and natural conditions. LOTT is already at advance treatment
Impact of shifting LOTT outfall	Difference in predicted DO under existing condition with LOTT at different locations(north of Priest Point park and near Boston Harbor) and natural conditions
Reduce external anthropogenic sources	Current conditions but with various reductions in external anthropogenic nitrogen loading
Reduce local nonpoint sources and turn LOTT OFF in July - September	Current conditions without dam and with LOTT turned OFF between July-Sept period and with different non-point N-reductions
Reduce local nonpoint sources and turn LOTT OFF in March - September	Current conditions without dam and with LOTT turned OFF between Mar-Sept period and with different non-point N-reductions
Sensitivity to reflux	Current conditions with WWTP = 0, but with existing non-point sources, with different reflux factors 5%, 10% and 20%
Potential recreational boater loads	Estimate potential nitrogen loads from recreational boaters in Budd Inlet
Potential marina loads	Estimate potential nitrogen loads from vessels at Budd Inlet marinas
Shellfish for restoration	

Table 3. Supplemental Capitol Lake management scenarios evaluated with calibrated models

Scenario	Description
Reduce watershed phosphorus loads	Current conditions with the dam but nonpoint anthropogenic phosphorus load to the lake reduced by 10%, 20% and 50%
Reduce Deschutes River temperature	Current conditions with the dam but Deschutes River temperature was reduced by 4 C for the months of July, August and September.
Alum treatment	Current conditions with the dam but the sediment fluxes for PO4 in the lake were reduced by using scalars in the sediment flux_wdg files of 0.9, 0.8, 0.5 and 0 for 10, 20, 50 and 100% reduction in PO4 fluxes, respectively
Dredge capitol Lake to nominal 13 ft	Managed lake alternative from the Capitol lake Adaptive Management Alternatives Analysis (2008-09)
Eliminate stormwater outfalls	Reduce the phosphorus contribution from urban areas

The natural conditions scenario was represented by modifying the existing conditions scenario. Natural conditions include removing the wastewater treatment plant loading and reducing the concentrations of water quality variables in the tributary streams to estimated natural concentrations as described in Roberts et al. (2012). Sediment fluxes and concentrations of water quality variables at the open boundary were also set to estimated natural conditions using the scalar methods described in the previous chapter. The Capitol Lake dam was also removed from the simulation and replaced by an open channel of grid cells at the location of the dam (Figure 6).

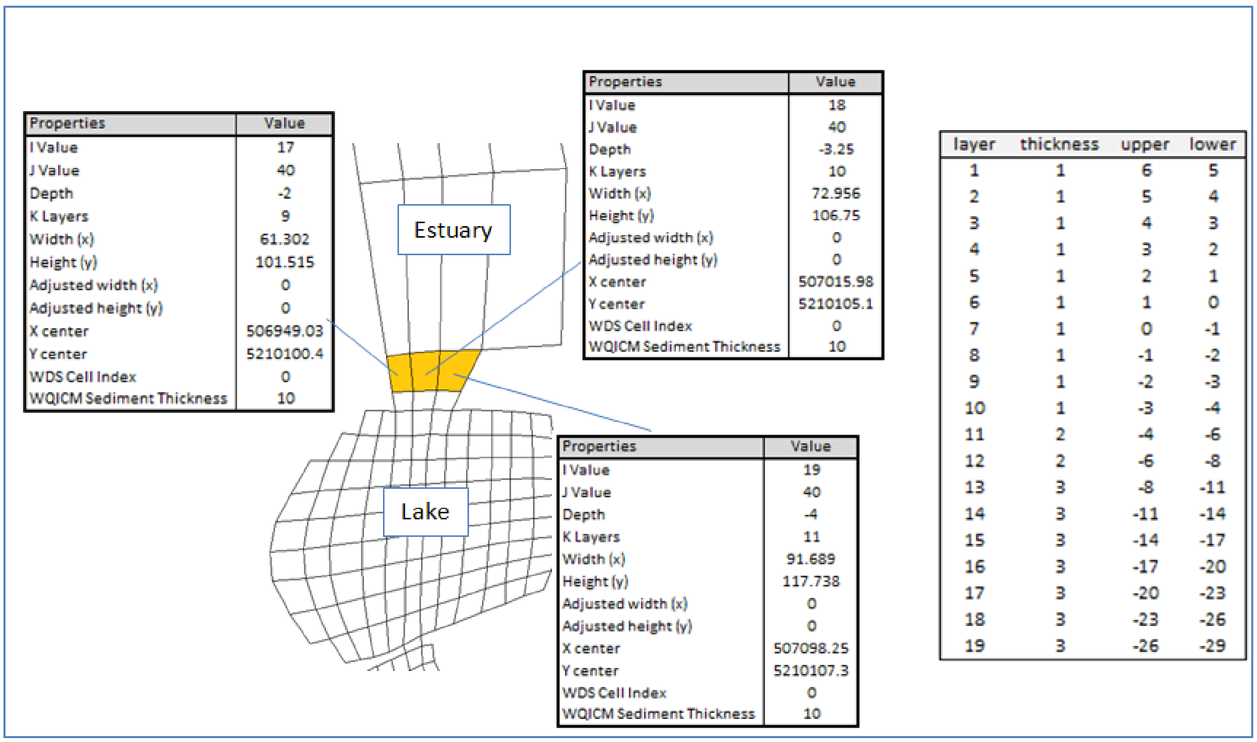


Figure 6. The open channel of grid cells between Capitol Lake and Budd Inlet used to represent a hypothetical natural estuary.

All depths, widths, heights and X and Y coordinates (UTM zone 10 map projection) are in meters.

Budd Inlet Scenarios

Natural conditions for dissolved oxygen in Budd Inlet

The natural conditions scenario is the baseline that is compared to all of the other scenarios. It represents the predicted conditions in the absence of any anthropogenic influence from loading of point sources or nonpoint sources, and a natural estuary in the place of Capitol Lake with no dam between Capitol Lake and Budd Inlet.

The predicted minimum DO in Budd Inlet and the natural estuary under natural conditions is shown in Figure 7. The minimum DO under natural conditions is predicted to fall below the water quality standard in portions of Budd Inlet, with lowest DO predicted in East Bay.

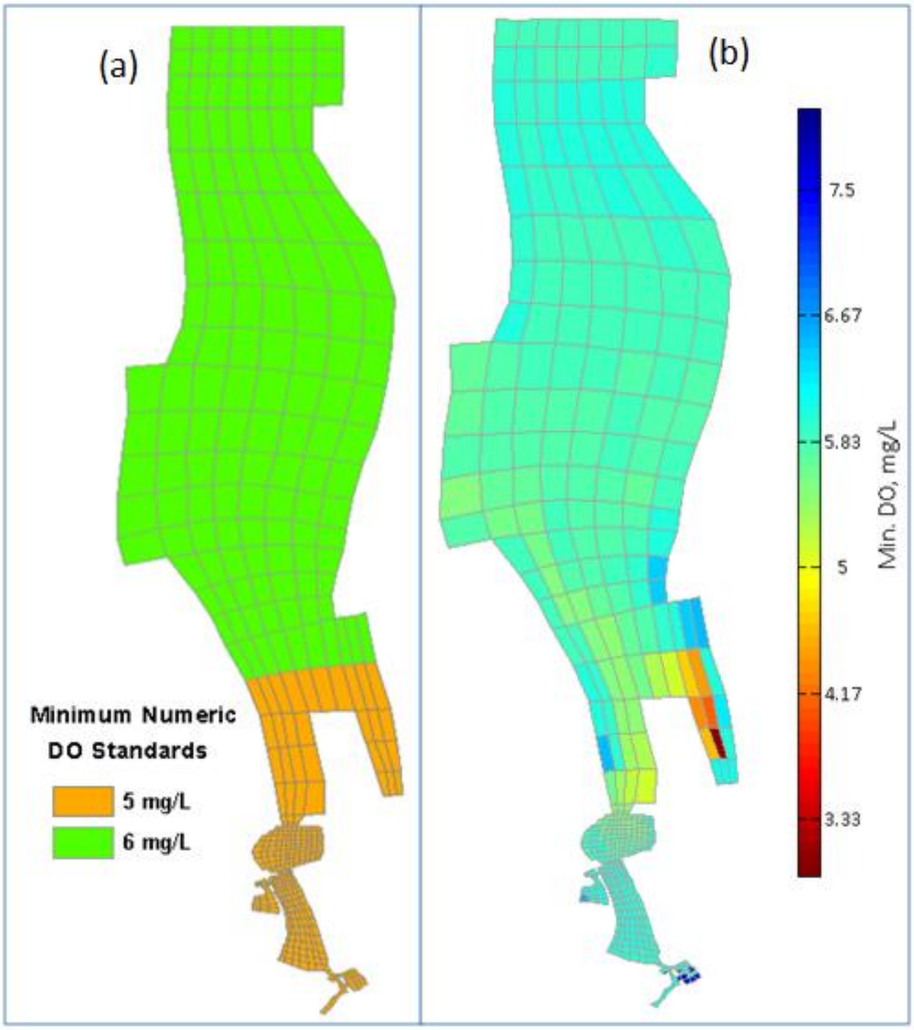


Figure 7. a) Water quality standards for DO in Budd Inlet and a natural estuary, and b) predicted minimum DO (mg/L) under natural conditions without the Capitol Lake dam.

Cumulative human impacts

The depletion of DO in Budd Inlet due to the currently existing conditions was evaluated by comparing the simulations of current conditions under existing anthropogenic loading and the presence of the Capitol Lake dam with natural conditions with natural loading and no dam (Table 2). The cumulative effects of all human activities cause DO violations >0.2 mg/L throughout most of southern and central Budd Inlet. The colors in Figure 8 represent the worst depletion in any vertical layer during the simulation period. However, impacts >0.2 mg/L occur throughout the critical period of September. The combined effects of human activities have the worst impact on East Bay. Other regions of Budd Inlet receive larger amounts of human nutrient inputs. East Bay has very sluggish circulation. Individual effects are described further below. DO depletion of up to about 3 mg/L was predicted at the critical location in East Bay, with widespread DO depletion greater than 1 mg/L throughout inner Budd Inlet (Figure 8, maximum DO depletion of 3.1 mg/L). The model grid cells with no color in the figure do not have zero human impacts. Instead, the human impacts are <0.2 mg/L.

The additional scenarios listed in Table 2 were evaluated to estimate the contribution to DO depletion from each of the various anthropogenic influences.

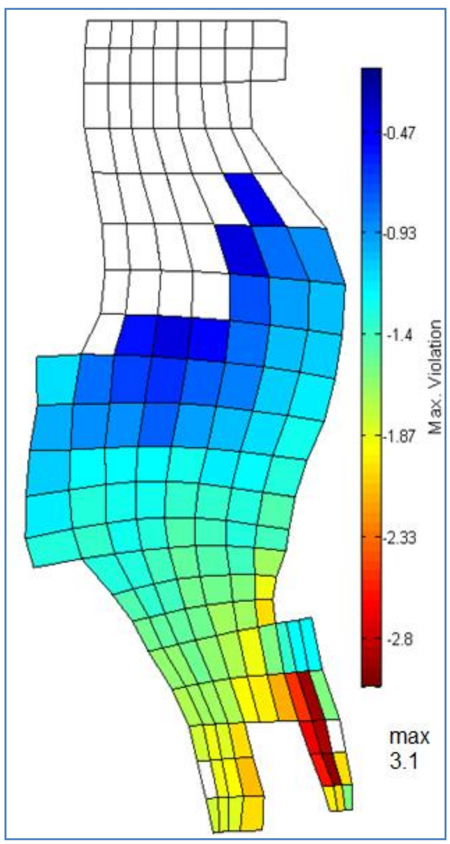


Figure 8. DO depletion (mg/L) caused by the cumulative effect of all anthropogenic influences including Capitol Lake dam and the current anthropogenic loading sources.

Effect of the Capitol Lake Dam

The effect of the dam on depletion of DO in Budd Inlet was evaluated using a scenario that was identical to the natural conditions with the exception that, instead of a free-flowing channel, the existing dam was included in the simulation. This scenario isolates the effect of the dam on DO depletion with only natural nitrogen loads from the Pacific Ocean and watersheds.

The dam caused up to about 2 mg/L in DO depletion (Figure 9, maximum DO depletion of 1.8 mg/L at the critical location in East Bay), with widespread and continuous depletion of around 1 mg/L in the bottom layer of the water column predicted throughout inner Budd Inlet south of Priest Point for extended periods during July-September.

The depletion of DO caused by the dam is due to a combination of factors. First, the dam creates a pulsed flow that alters circulation in southern Budd Inlet. Second, the dam and the lake alter the concentrations and loads of nitrogen and carbon. The assimilation of inorganic nitrogen by freshwater plants (e.g., phytoplankton) with corresponding production of organic carbon alters discharges into Budd Inlet. These factors were evaluated separately.

In the first run, a simulated dye tracer was added to the East Bay grid cells, and the model was run for the simulation period with and without the dam in place. A time-series of dye concentration in the bottom layer of the critical East-Bay cell was plotted for both the scenarios (Figure 10). The plot shows that there is more dye remaining in the bottom layer of the critical cell when the dam is in place compared to that when the dam is removed (i.e., estuary). Higher concentration of dye would signify longer flushing times or higher residence times. This comparison shows that the residence time of water at the critical location in East Bay is significantly longer with the dam. A longer residence time creates more stagnant conditions and allows for greater consumption of DO by biological processes of decomposition of organic matter in the water and sediment and water column respiration.

The second analysis compared the concentration of total organic carbon at the location of the outflow from Capitol Lake with and without the dam in place. The TOC concentration, with a seasonal peak as high as 5 mg/L compared with 2 mg/L without the dam, is significantly higher due the dam (Figure 11a). Organic carbon increases due to the growth of freshwater plants, both phytoplankton and macrophytes) in Capitol Lake.

The third analysis compared the concentration of dissolved inorganic nitrogen and organic nitrogen at the location of the outflow both with and without the dam in place. The growth of plants in the lake converts nearly all of the dissolved inorganic nitrogen into organic nitrogen in plant cells and detritus. Nearly all of the total nitrogen and organic matter produced by plants in Capitol Lake appeared to quickly discharge into Budd Inlet during 1997 (Figure 12) and 2000-2001 (Figure 13) without being significantly trapped in the lake (based on samples collected by the LOTT BISS during 1997 and Miller Brewing Company in 2000-2001 using total nitrogen estimated as the sum of total Kjeldahl nitrogen and nitrate+nitrite as nitrogen).

Ecology collected samples during 2003-2004 showing there was some significant reduction in the total persulfate N (TPN) between upstream and downstream locations in Capitol Lake (Figure 14). The apparent reduction in TPN during 2003-2004 could be due to low recovery considering that two out of the three studies did not use the TPN method and they show very little retention of total N in Capitol Lake. Ecology's Manchester Laboratory suggests that the TPN method is most suitable for fairly clear samples, and the N content of plant or detritus fragments may not be effectively recovered during the test (personal communication, Karin Feddersen, 9/29/2014).

The production of organic carbon is the process that is responsible for depletion of DO in Budd Inlet. This process is significantly more efficient in Capitol Lake compared with a natural estuary. The TOC produced within the lake leads to a greater depletion of DO in Budd Inlet. Decomposition of the excess organic matter is the mechanism.

The increased production of oxygen-demanding organic carbon combined with longer residence times for decomposition to occur leads to significantly greater depletion of DO due to the presence of the dam. This effect occurs even with no additional human inputs to Budd Inlet from local rivers, local wastewater treatment plants, or human sources external to Budd Inlet.

The increased depletion of DO in Budd Inlet due to the dam is significantly greater in the bottom water (Figure 15) compared with the surface water (Figure 16). This finding further indicates that the cause of the increased depletion of DO is an increase in oxygen consumption due to degradation of the excess organic matter produced in the lake. The increased depletion of DO due to the dam occurs throughout inner Budd Inlet throughout July through September with extended periods of greater than 1 mg/L of DO depletion across a wide area south of Priest Point (Figure 15).

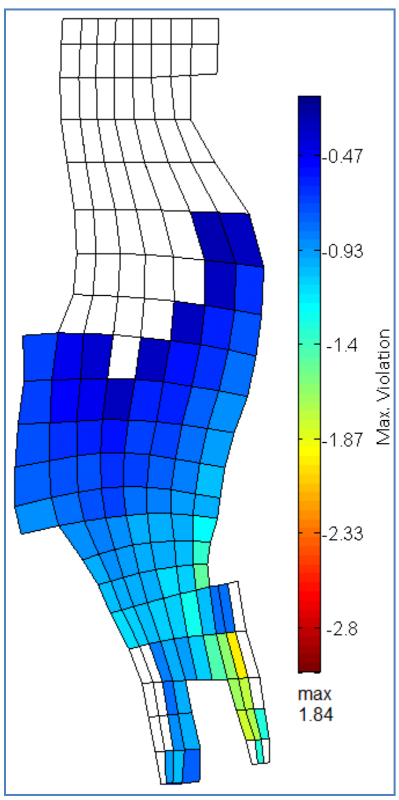


Figure 9. DO depletion (mg/L) caused by the Capitol Lake dam with no anthropogenic loading sources.

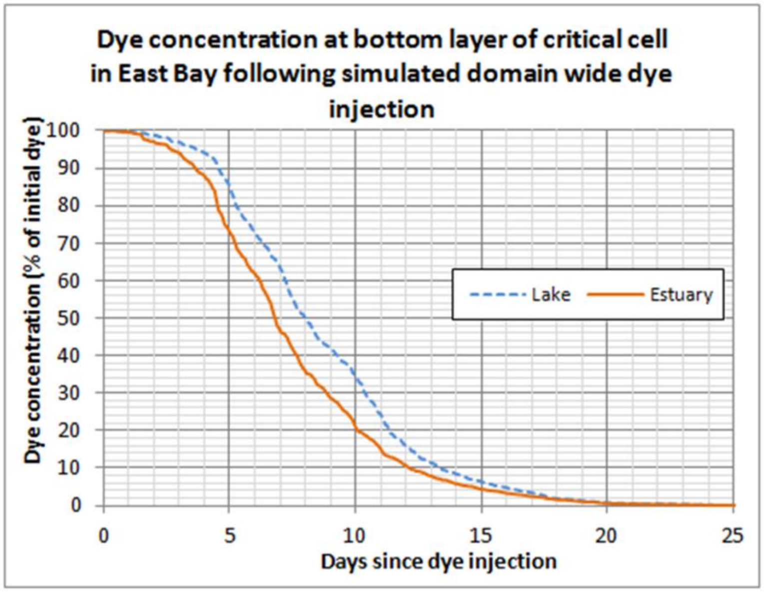


Figure 10. Time-series dye concentration at the critical East Bay grid cell under Lake (with the dam) and Estuary (without the dam) scenarios.

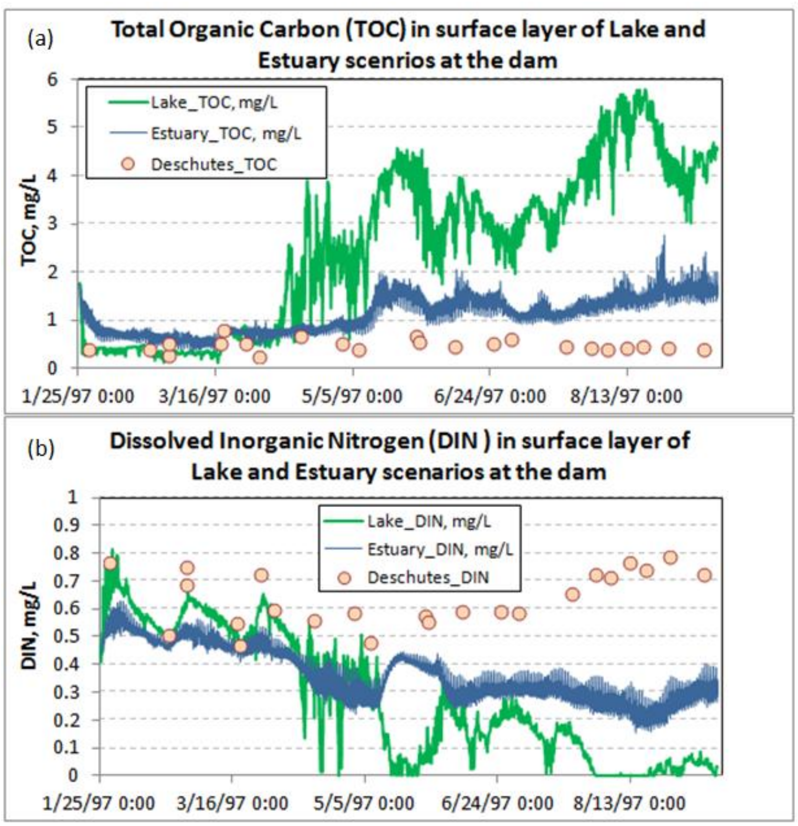


Figure 11. a) Total organic carbon (TOC) and b) dissolved inorganic nitrogen (DIN) concentrations at the location of the Capitol Lake dam under Lake (with the dam) and Estuary (without the dam) scenarios compared with concentrations in the Deschutes River.

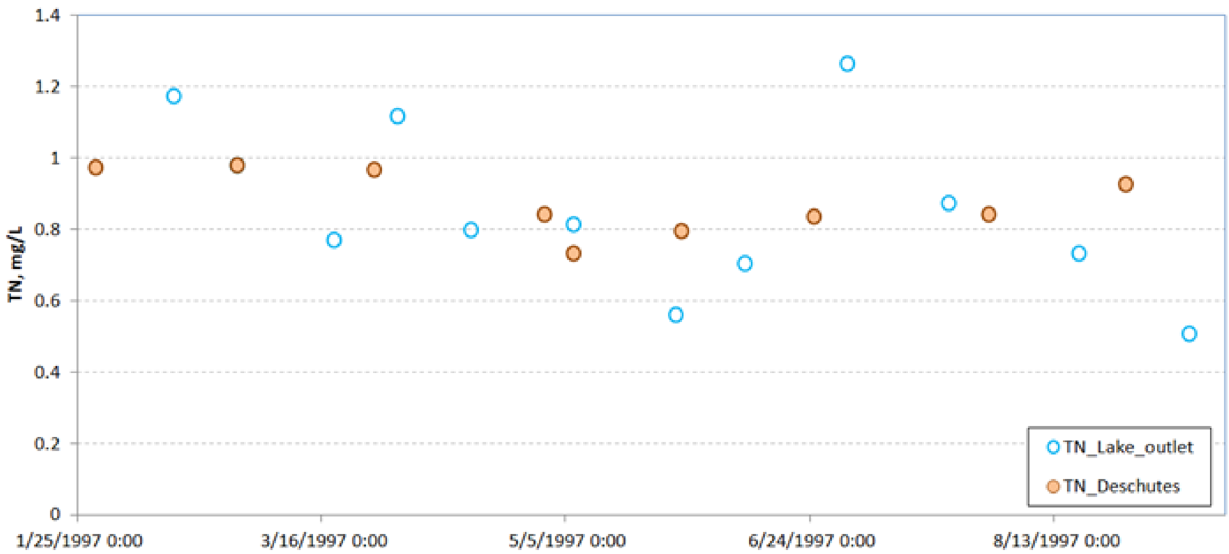


Figure 12. Total nitrogen concentration in the Deschutes River and at the location of the Capitol Lake outlet near dam during 1997. Source: Evans Hamilton Capitol Lake data used in the 1997 Budd Inlet Scientific Study and Ecology continuous monitoring data for Deschutes River at E-street ,

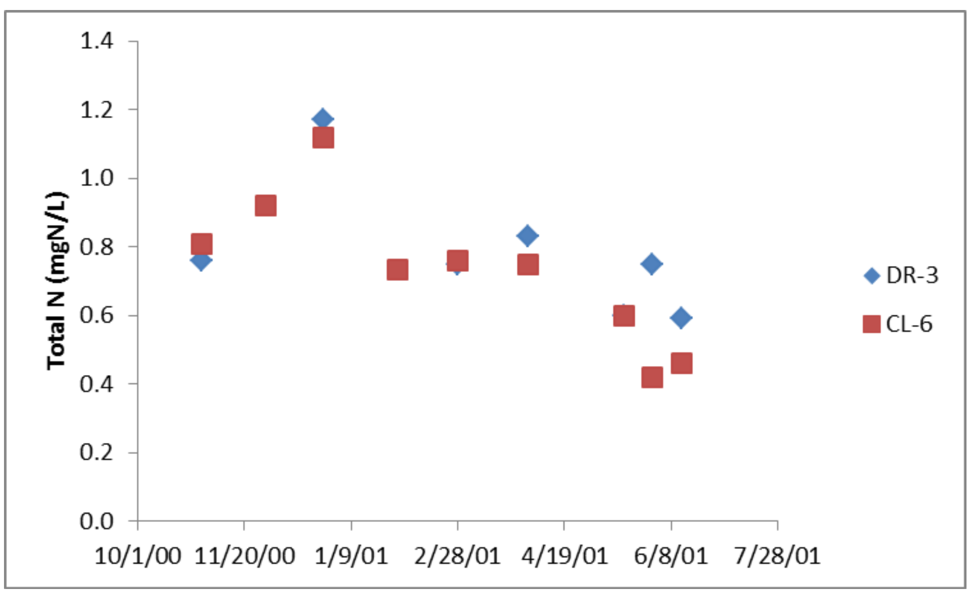


Figure 13. Total nitrogen concentrations in the Deschutes River (DR-3) and Capitol Lake near the dam (CL-6) during 2000-2001. Source: CH2M-Hill (2001).

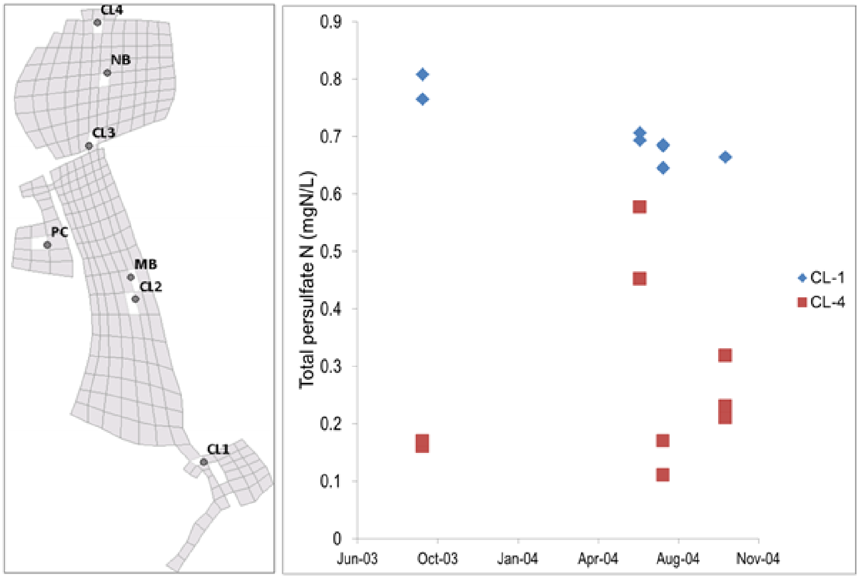


Figure 14. Total persulfate N at two locations in Capitol Lake during 2003-2004. Source: Roberts et al. (2008)

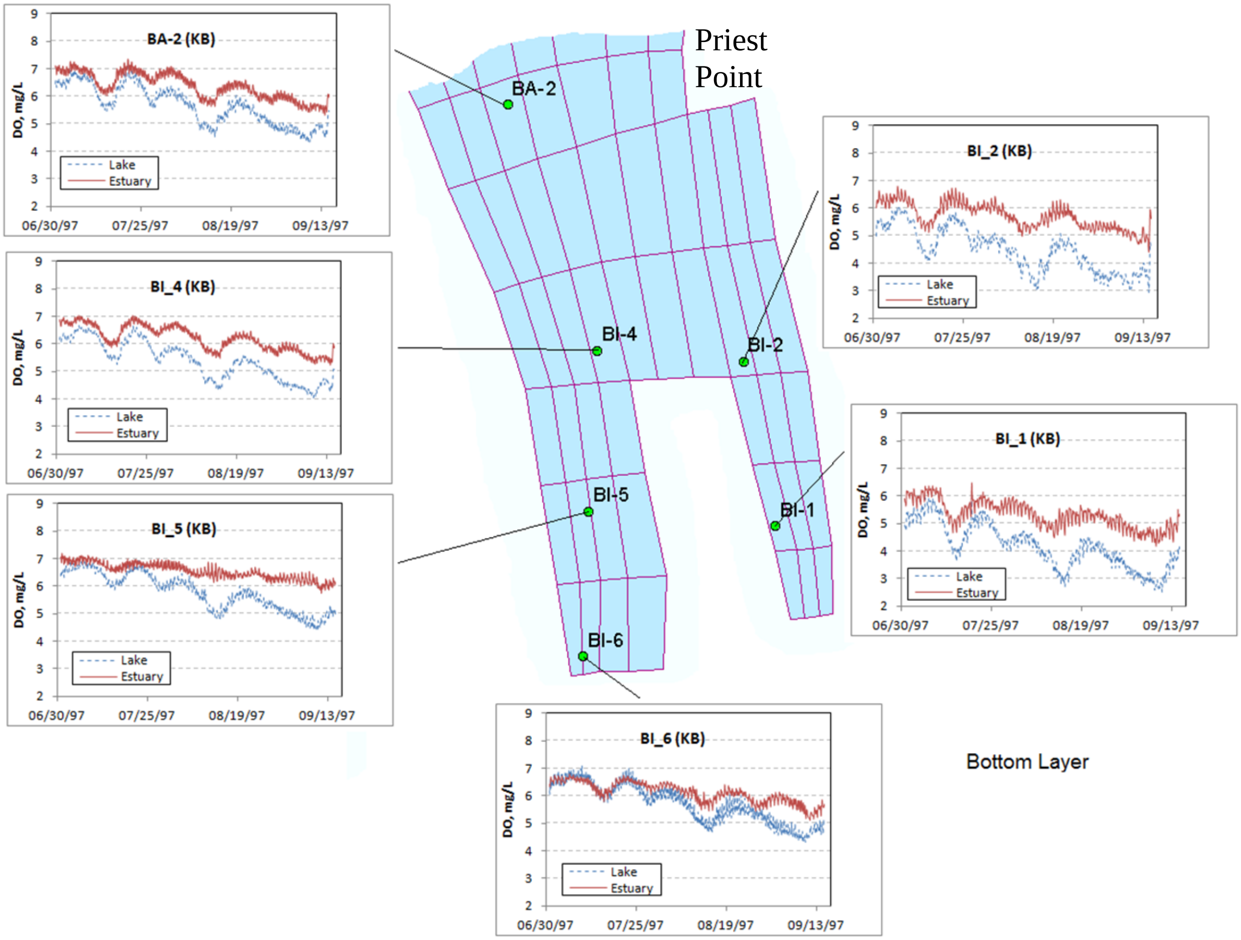


Figure 15. Predicted DO in the bottom layer at selected locations in Budd Inlet with current anthropogenic loading with the Capitol Lake dam (blue-dashed lines labeled "Lake") and without the Capitol Lake dam (red line labeled "Estuary").

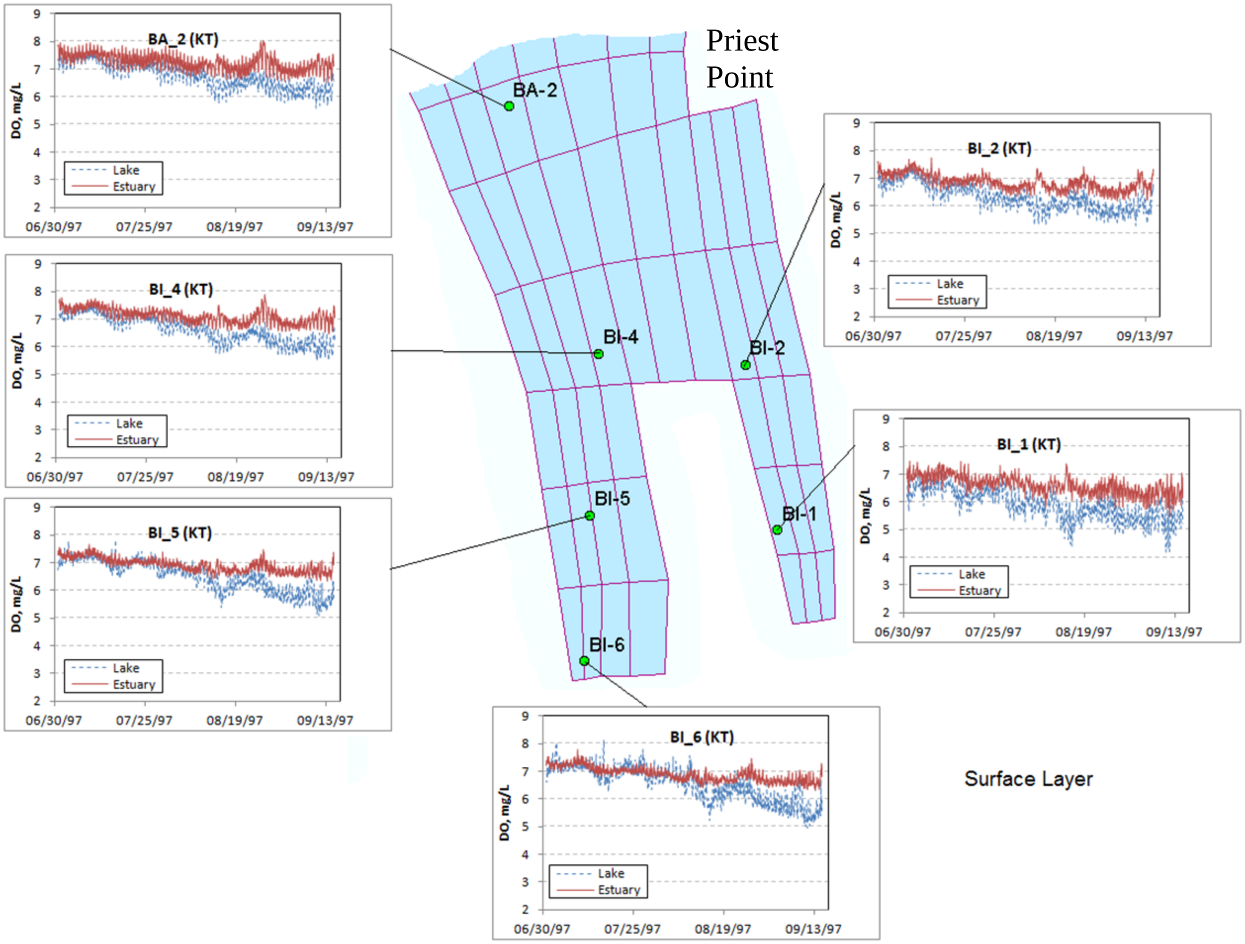


Figure 16. Predicted DO in the surface layer at selected locations in Budd Inlet with current anthropogenic loading with the Capitol Lake dam (blue-dashed lines labeled “Lake”) and without the Capitol Lake dam (red line labeled “Estuary”).

Combined effect of local and external human nutrient sources

The effect of all anthropogenic loading of nutrients on depletion of DO in Budd Inlet was evaluated using a scenario that was identical to the existing conditions with the exception that the existing dam was not included in the simulation. This scenario isolates the effect of the combined total anthropogenic nutrient loads on DO depletion.

Anthropogenic loading in this scenario is contributed by point sources and non-point sources discharging into Budd Inlet, in addition to loading from sources outside of Budd Inlet entering across the open boundary. The total anthropogenic load into Budd Inlet under this scenario was approximately 1980 Kg/day (April –Sept) above the loading under natural conditions. The combined effect of all anthropogenic loads causes portions of southern Budd Inlet to violate the DO standard. The largest impact is up to about 0.6 mg/L depletion of DO at the critical location at East Bay (Figure 17). The DO impacts reflect a combination of circulation patterns and nitrogen loading.

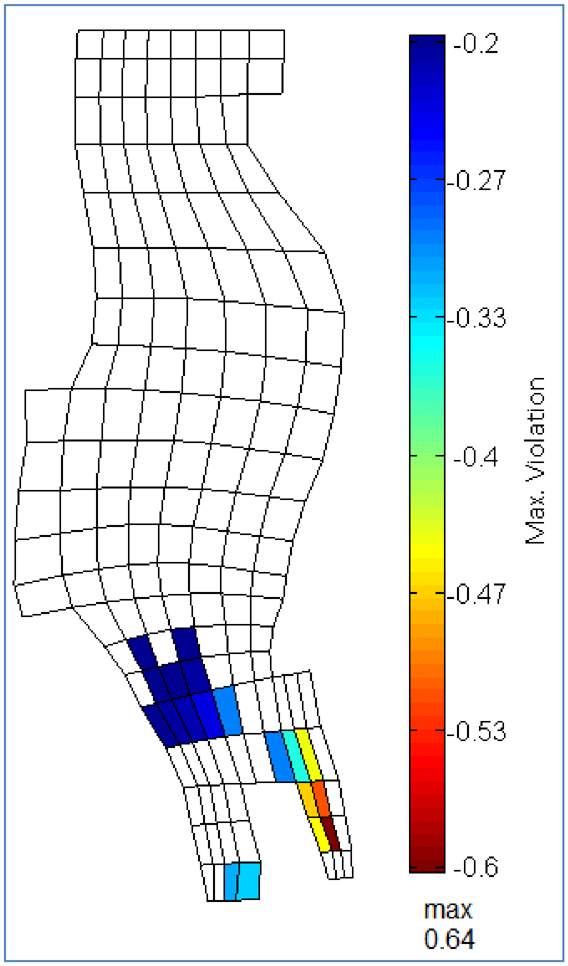


Figure 17. DO depletion (mg/L) caused by the combined effect of all anthropogenic nutrient loads with no Capitol Lake dam.

Sources external to Budd Inlet

In this project we define external sources as the anthropogenic loading sources that originate from outside of Budd Inlet and are transported into Budd Inlet across the open boundary. Local sources are defined as the anthropogenic loading sources that discharge directly into Budd Inlet.

The effect of external sources on depletion of DO in Budd Inlet was evaluated using a scenario with no dam and no local anthropogenic nitrogen sources. Only natural sources from north of Budd Inlet and from the local sources were included. The total external anthropogenic load was estimated at 1488 Kg/day (April – Sept). This scenario isolates the effect of the external anthropogenic nutrient loads on DO depletion.

The external anthropogenic loads alone cause DO violations in portions of East Bay (Figure 18b). The largest depletions are about 0.4 mg/L depletion of DO at the critical location at East Bay (Figure 18b). In contrast to the effect of the combined total anthropogenic loads (Figure 17 and Figure 18a), the external sources contribute to a little over half of that total DO depletion caused by the combination of local and anthropogenic sources.

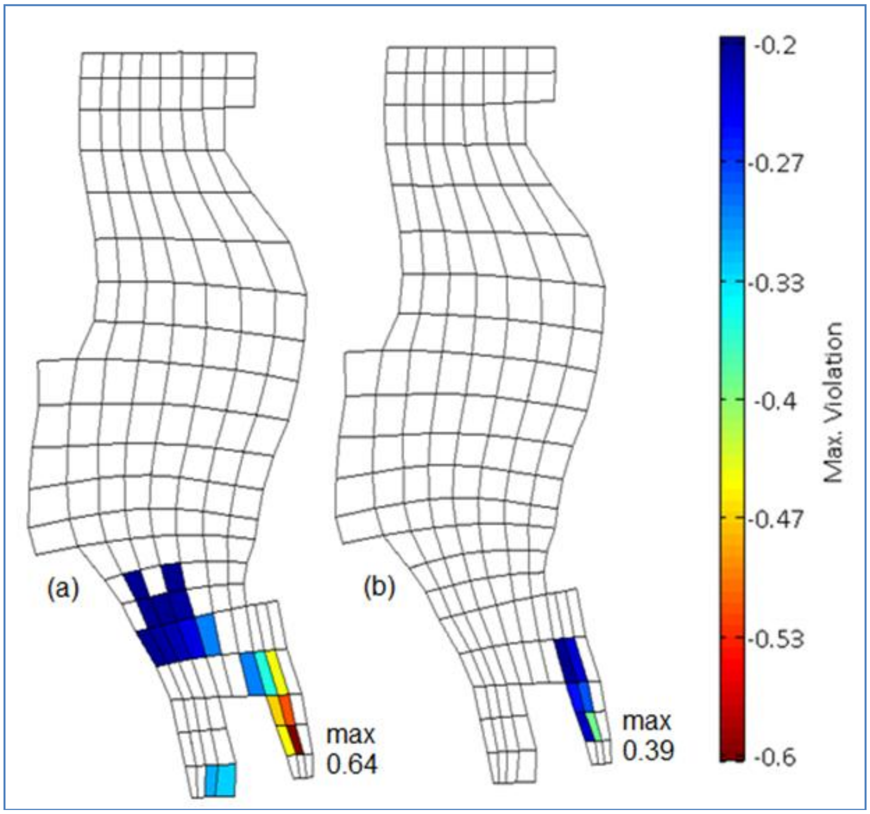


Figure 18. a) DO depletion (mg/L) without the Capitol Lake dam with the external anthropogenic sources outside of Budd Inlet plus the local anthropogenic sources (same as Figure 17), and b) with only the external anthropogenic sources outside of Budd Inlet with no local anthropogenic sources.

Reduce local nonpoint sources

The effect of local upland (nonpoint) sources on depletion of DO in Budd Inlet was evaluated using scenarios that were compared with existing load impacts but with no dam in place. The model was used to simulate the effect of reducing local upland sources by 20% (total anthropogenic load reduced by 59 Kg/d during April -Sept) and 50% (total anthropogenic load reduced by 148 Kg/d during April - Sept). These scenarios isolate the effect of reducing local upland loads on DO depletion.

Reducing local upland sources (nonpoint) is predicted to make small improvements in the depletion of DO in Budd Inlet (Figure 19b and c) compared with the current condition (Figure 19a). However, while reducing nonpoint sources could decrease the portions of Budd Inlet that violate standards, the critical East Bay cell would still experience violations of 0.6 mg/L.

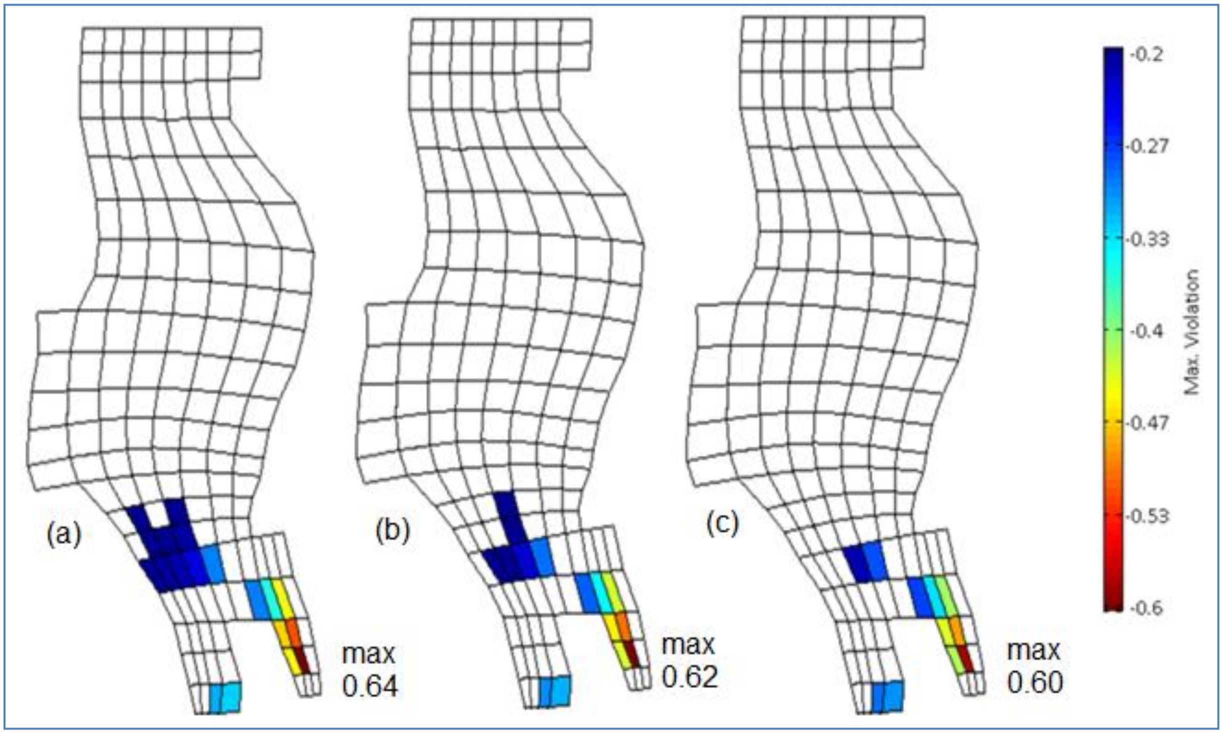


Figure 19. a) DO depletion (mg/L) without the Capitol Lake dam with the existing anthropogenic sources (same as Figure 17), b) with 20% reduction in local anthropogenic nonpoint sources, and c) with 50% reduction in local anthropogenic sources.

Advanced treatment to three small wastewater treatment plants discharging to Budd Inlet

In addition to LOTT, three small wastewater treatment plants discharge to Budd Inlet. All three provide secondary treatment but not advanced treatment that reduces nitrogen as at LOTT. We evaluated the benefits of reducing effluent nitrogen concentration to 3 mg/L during April - Sept period at the three smaller treatment plants while LOTT at existing treatment level. This equates to a reduction in anthropogenic load from existing load by only 4 Kg/d.

Adding advanced treatment at three small WWTPs does not significantly change predicted DO depletion (Figure 20). The small WWTPs currently represent a very small load of N compared with LOTT (Figure 21a). Advanced treatment would reduce the N loading from the small plants but translates to <0.01 mg/L benefit. Existing loading from external loads, local river inputs, and LOTT are much higher. For local wastewater treatment plants, LOTT would still represent the large majority of loading (Figure 21b).

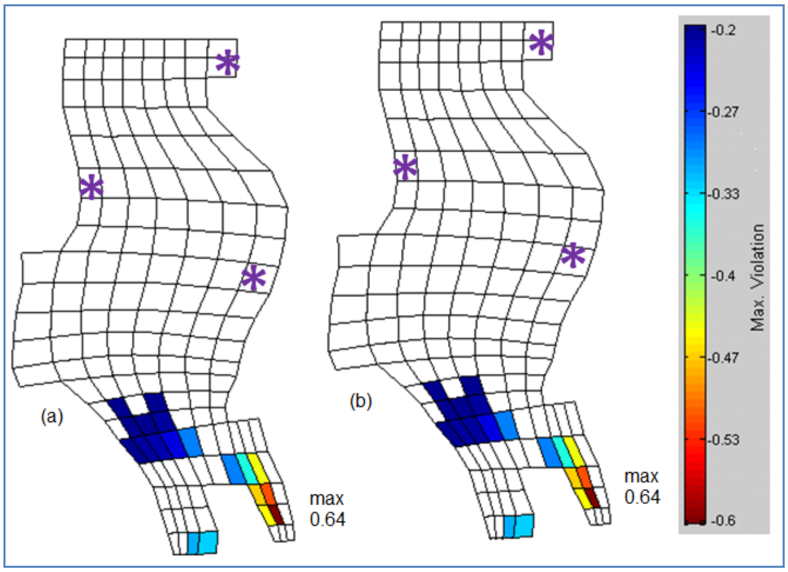


Figure 20. a) DO (mg/L) depletion without the Capitol Lake dam with existing anthropogenic sources (same as Figure 17), and b) with advanced treatment for N removal at the three small WWTPs discharging to Budd Inlet.

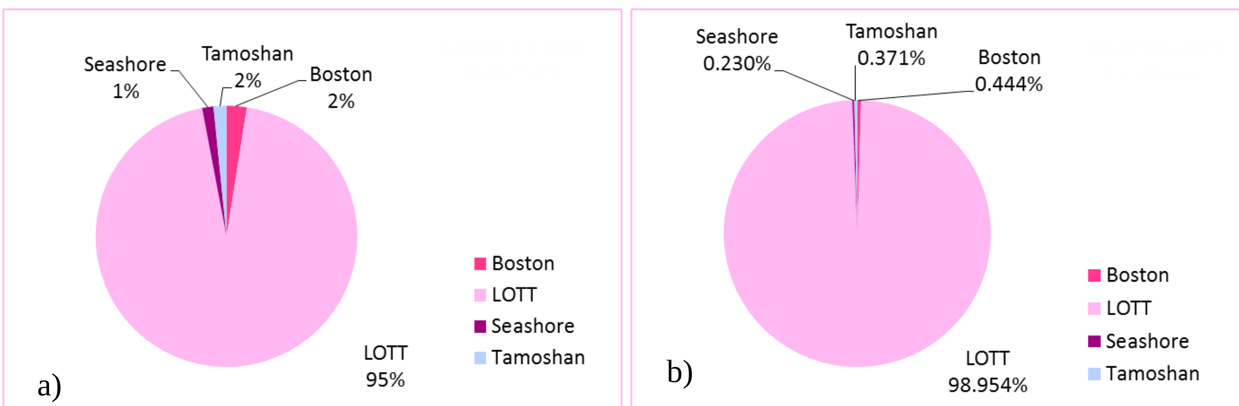


Figure 21. a) The proportion of point source loading of N from the various local point sources under the existing condition, and b) with advanced treatment at the three small WWTPs (Seashore Villa, Tamoshan, and Boston Harbor).

Shift LOTT outfall north of Priest Point Park or to Boston Harbor

We evaluated the potential benefit of moving the discharge location of the LOTT outfall to locations north of the present outfall. Two potential locations were considered (Figure 22a): 1) north of Priest Point Park or 2) near Boston Harbor. The loading was not changed.

Shifting the outfall location would not improve oxygen significantly. Moving the outfall to the location north of Priest Point Park is predicted to decrease the magnitude of DO depletions in some areas, but would increase the areal extent of predicted violation of the DO standard (Figure 22c compared with b).

Moving the outfall to the location near Boston Harbor is predicted to decrease the magnitude of DO depletions, and decreases the areal extent of predicted violation of the DO standard (Figure 22d compared with b). Several areas are predicted to remain with violation of the DO standard.

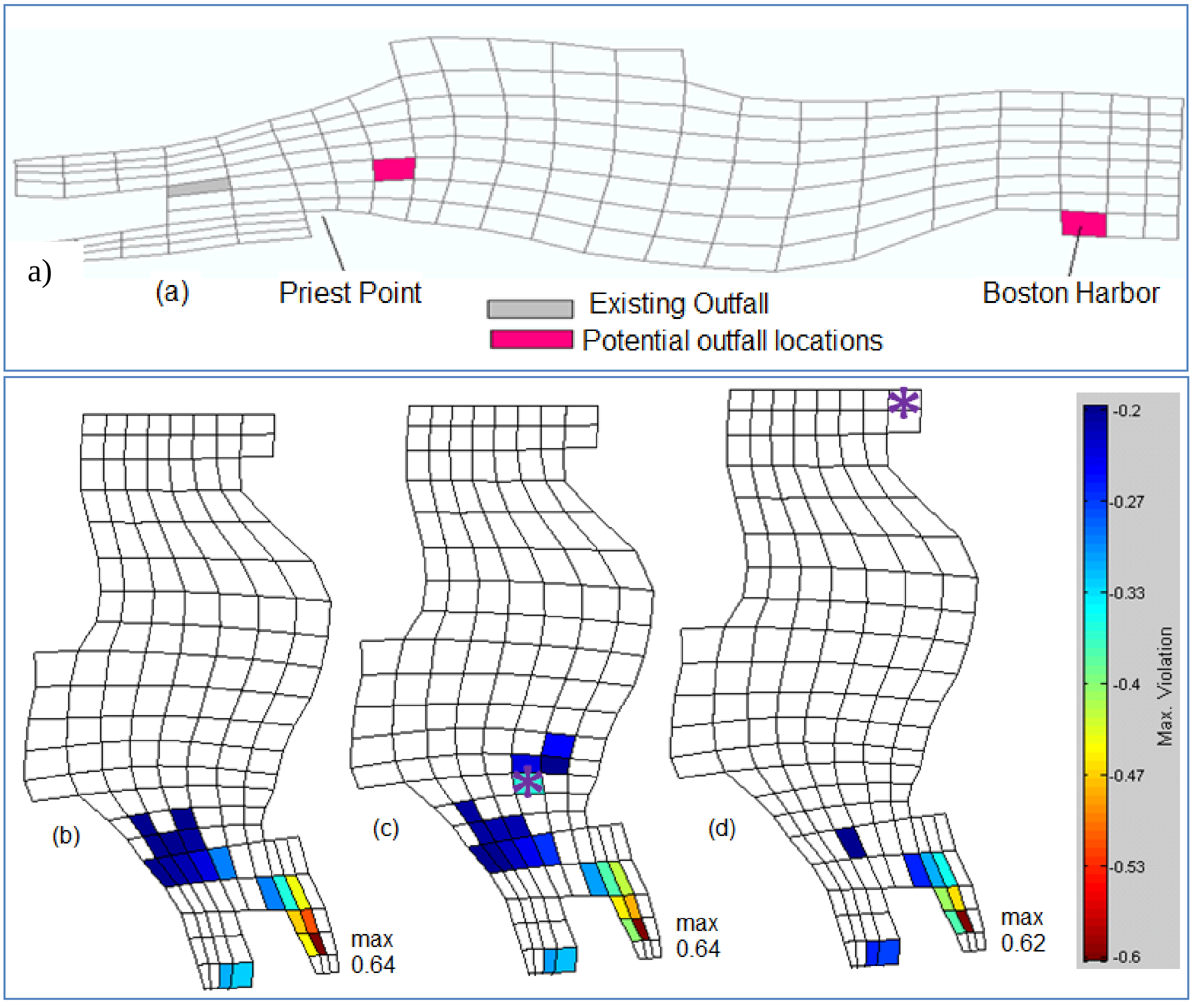


Figure 22. a) alternative potential outfall locations, b) DO depletion (mg/L) without the Capitol Lake dam with existing anthropogenic sources (same as Figure 17), c) with the LOTT outfall moved to north of Priest Point Park, and d) with the LOTT outfall moved to Boston Harbor.

Reduce sources external to Budd Inlet

External sources are anthropogenic loading sources that originate from outside of Budd Inlet that are transported into Budd Inlet across the open boundary. Local sources are defined as the anthropogenic loading sources that discharge directly into Budd Inlet.

We evaluated potential benefits of compared with existing loading conditions but no dam. Local anthropogenic sources were removed, and various amounts of reduction of external loading was assumed (10% and 50% reduction). These scenarios isolate the effect of reducing the external anthropogenic nutrient loads on DO depletion.

Reducing external sources alone by 10 or 50% would not eliminate DO violations. Portions of southern Budd Inlet would violate the DO criteria. However, Figure 23 shows that reducing external anthropogenic loading has the potential to reduce the magnitude and extent of DO depletion (compared with Figure 17).

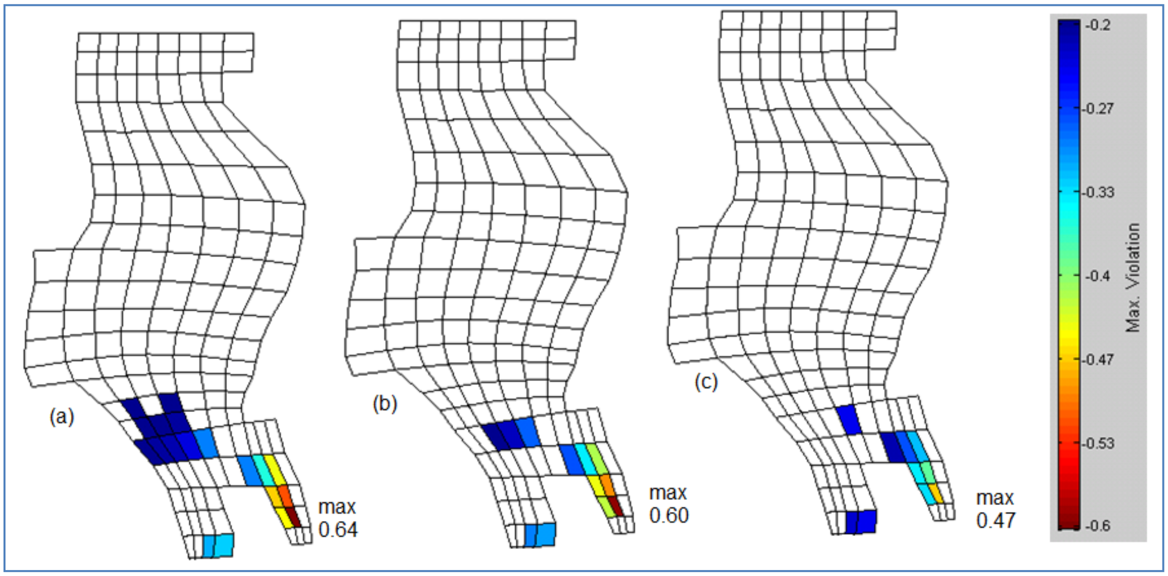


Figure 23. a) DO depletion (mg/L) without the Capitol Lake dam with existing local anthropogenic sources, (b) with 10% reduction (149 Kg/d) in external anthropogenic sources, and (c) with 50% reduction (744 Kg/d) in external anthropogenic sources.

Reduce local nonpoint sources and LOTT discharge off seasonally

No single management action would eliminate all DO violations. We also analyzed scenarios that consider multiple management actions.

The effect of reducing local upland (nonpoint) sources in combination with seasonal discharge from LOTT on improvement in the depletion of DO in Budd Inlet was evaluated using scenarios that were identical to the existing conditions with the exception that the existing dam was not included in the simulation, discharge from the LOTT outfall was assumed to be zero for a selected season, and the local upland sources were reduced by 0%, 20% and 50%.

Two optional seasons for no-discharge from LOTT were evaluated with the various assumed reductions in local upland sources: 1) July-September (Figure 24), and 2) March-September (Figure 25). These scenarios isolate the combined effect of reducing local nonpoint loads on DO depletion with seasonal no-discharge from LOTT.

Reducing local nonpoint sources in combination with seasonal no-discharge from LOTT is predicted to make small improvements in the depletion of DO in Budd Inlet (Figure 24) compared with the current condition (Figure 25). However, DO violations would still occur, particularly in East Bay.

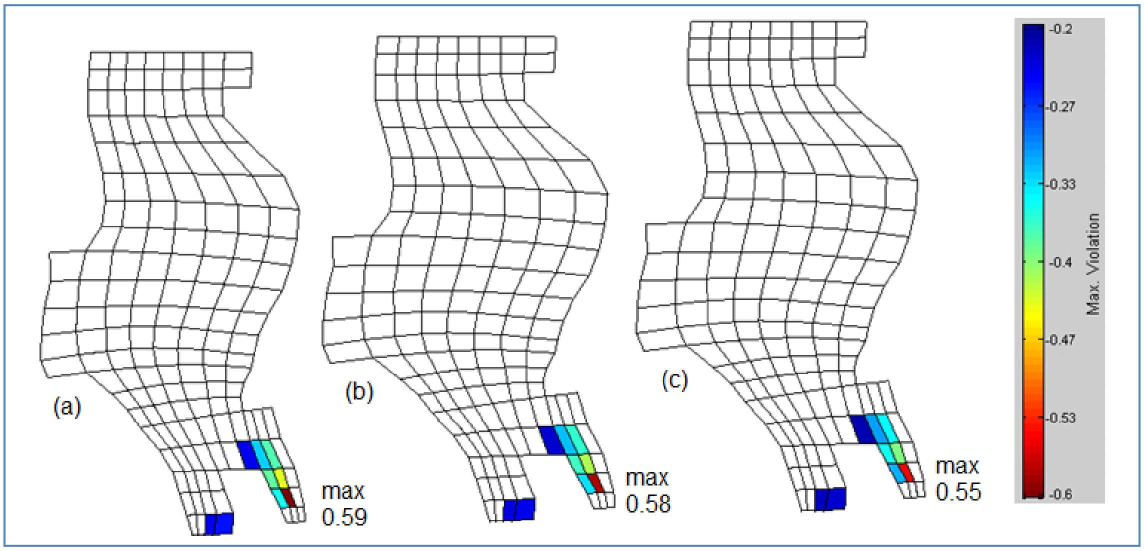


Figure 24. a) DO depletion (mg/L) without the Capitol Lake dam with no discharge from LOTT during July-September and no reduction in local nonpoint sources (total anthropogenic load = 1892 Kg/d), b) with 20% reduction of local nonpoint sources (load in (a) reduced by 59 Kg/d), and c) with 50% reduction of local nonpoint sources (load in (a) reduced by 148 Kg/d).

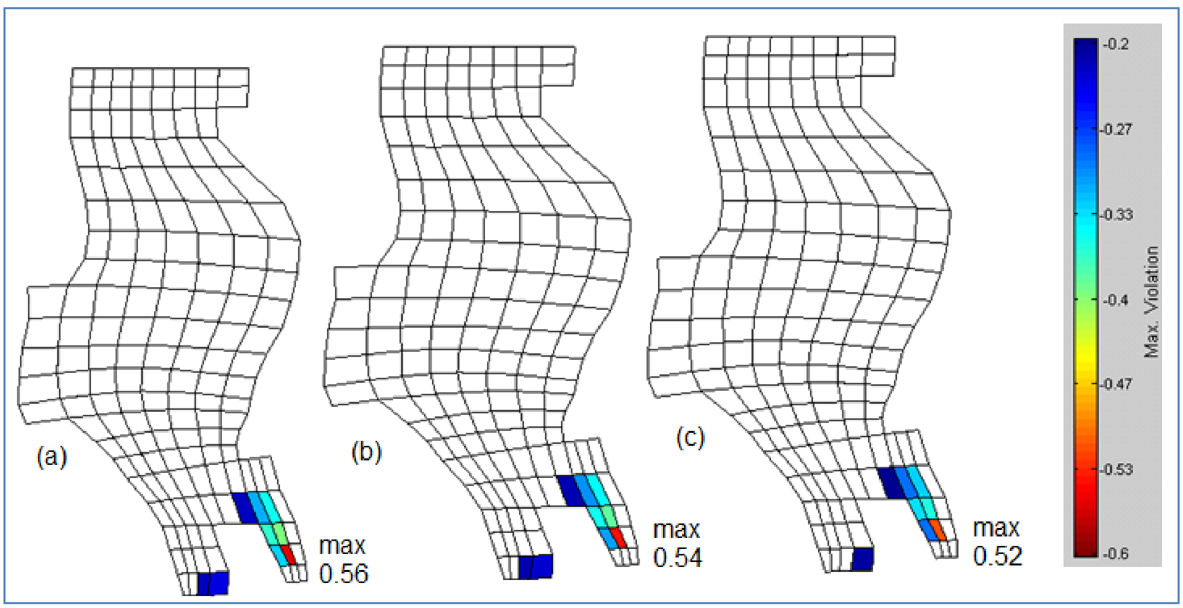


Figure 25 a) DO depletion (mg/L) without the Capitol Lake dam with no discharge from LOTT during March-September and no reduction in local nonpoint sources (total anthropogenic load = 1790 Kg/d), b) with 20% reduction of local nonpoint sources (load in (a) reduced by 59 Kg/d), and c) with 50% reduction of local nonpoint sources (load in (a) reduced by 148 Kg/d).

Sensitivity to reflux of local sources

Reflux is defined as the fraction of the loading into Budd Inlet that returns back into Budd Inlet after it leaves across the open boundary (Figure 26). The reflux fraction was estimated using the SPSDOS model by comparing two scenarios: 1) natural conditions, and 2) natural conditions plus existing (2007) loading from LOTT. The difference between incoming total N loads across the open boundary for these two scenarios was assumed to represent the amount of total N load from LOTT that was refluxed back into Budd Inlet across the open boundary. The ratio of the refluxed load to the total load from LOTT was assumed to represent the refluxed fraction of loading. The reflux fraction was found to be approximately 20% (i.e., about 20% of the load from LOTT re-enters Budd Inlet back across the open boundary after it leaves Budd Inlet).

We evaluated the sensitivity to uncertainty in the amount of reflux by trying the following various amounts: 5%, 10%, and 20%. For each range of assumed reflux we evaluated whether the reflux applied to only the local anthropogenic sources with point sources assumed to be absent (Figure 27), or whether it applied to all local anthropogenic sources including current point and nonpoint sources (Figure 28).

The predicted maximum DO depletion was found to be relatively insensitive to the reflux fraction between 5% and 20%. Although the maximum DO depletion was relatively sensitive to whether the anthropogenic load was only from nonpoint sources (Figure 27) versus the combined total of the current point and nonpoint sources (Figure 28), in the scenarios evaluated, the reflux amount was applied to both the point and non-point anthropogenic sources.

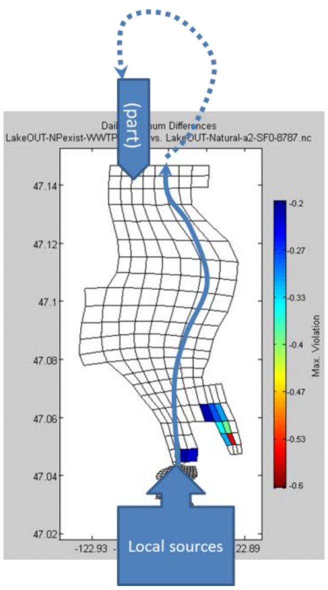


Figure 26. The definition of reflux is the fraction of local anthropogenic loading that re-enters back across the open boundary of Budd Inlet after leaving.

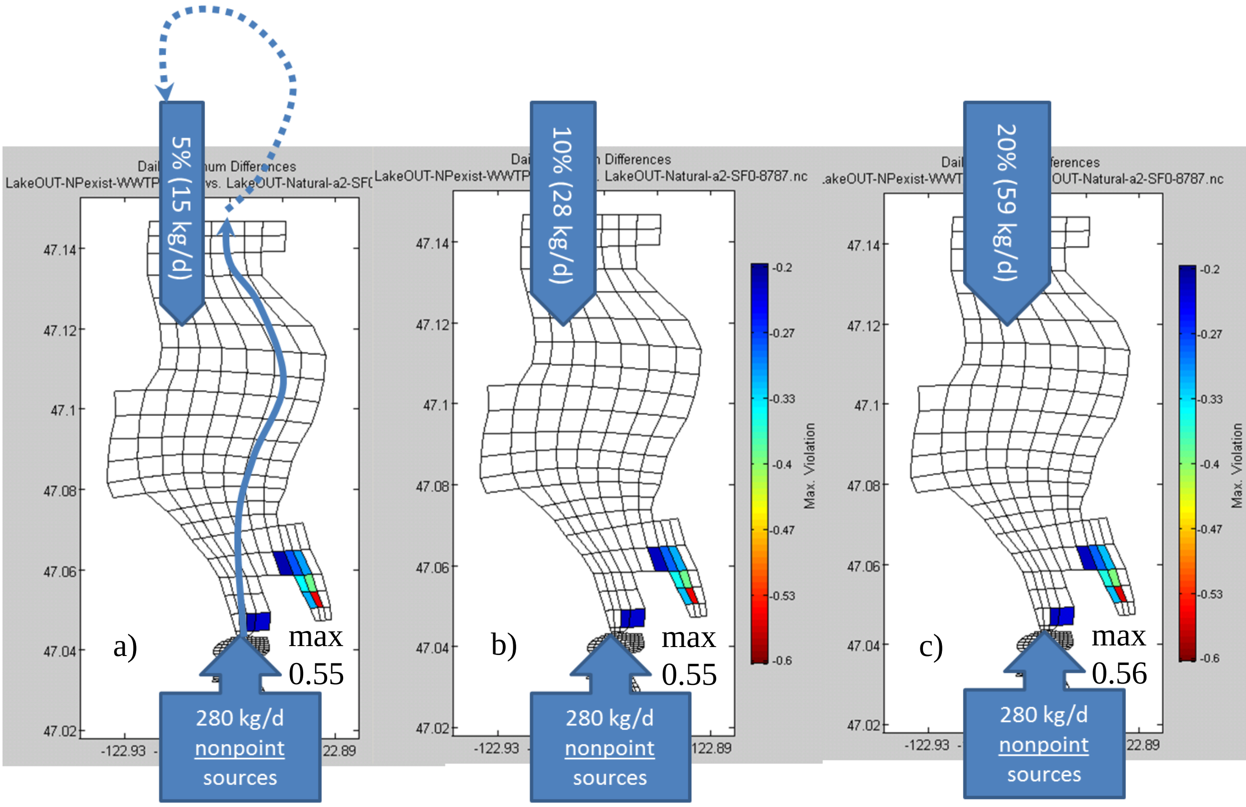


Figure 27. DO depletion (mg/L) with no Capitol Lake dam with a) reflux of 5% of the local nonpoint anthropogenic load, b) reflux of 10% of the local nonpoint anthropogenic load, and c) reflux of 20% of the local nonpoint anthropogenic load.

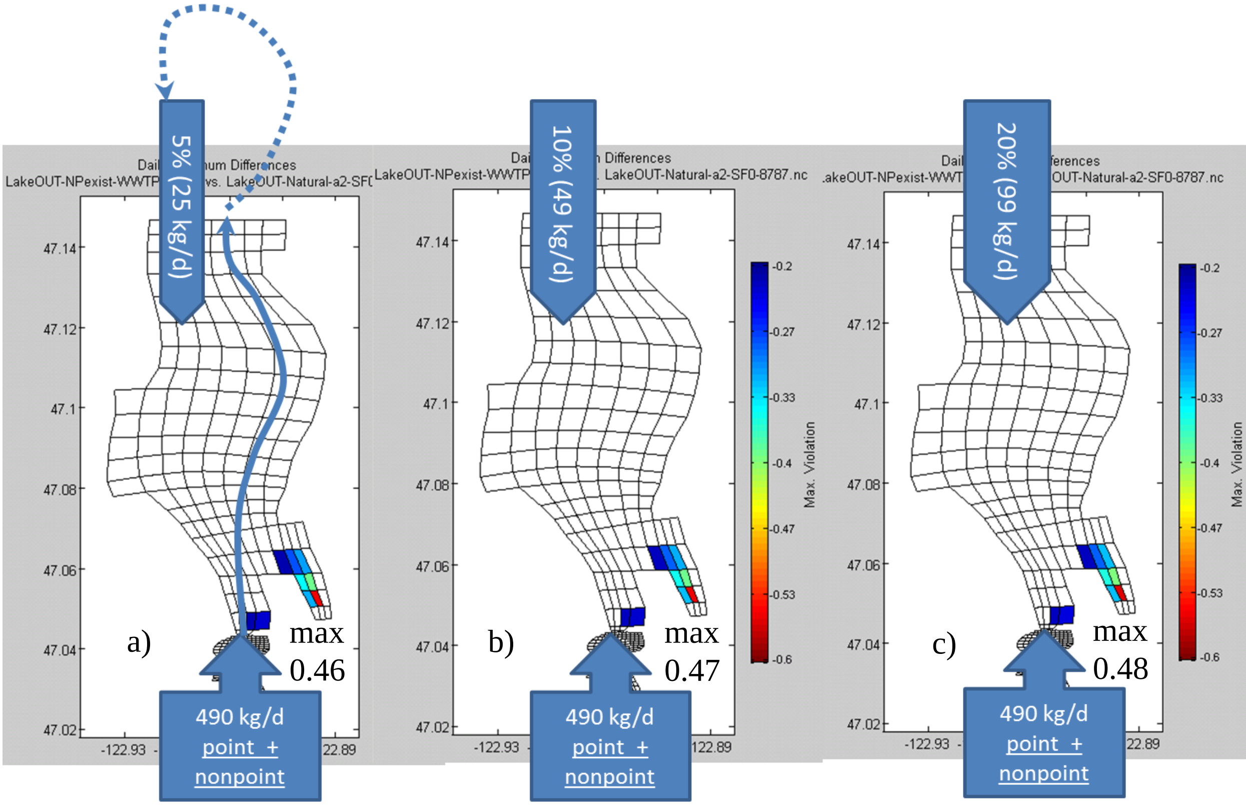


Figure 28. DO depletion (mg/L) with no Capitol Lake dam with a) reflux of 5% of the total local anthropogenic load, b) reflux of 10% of the total local anthropogenic load, and c) reflux of 20% of the total local anthropogenic load.

Potential recreational boater loads

We evaluated potential nutrient loads associated with recreational boaters' wastewater. No previous estimates are available for either the number of recreational boater days or the incidence of recreational boater wastewater discharging to Budd Inlet.

We developed a screening-level estimate for both annual average and summer peak usage (Table 4). These use a per capita load of 4.5 kg of total nitrogen per year based on a range of 2 to 6 kg-N/yr (EPA, 2002) and assumptions for the number of people and proportion of day recreating on Budd Inlet and the number of people releasing wastes to marine waters.

Table 4. Estimates for potential recreational boater wastewater discharged to Budd Inlet

Variable	Unit	Annual Average	Peak Summer
People using Budd Inlet per day	#/day	5	200
Proportion of day on Budd Inlet	% day	10%	30%
Proportion urinating overboard	%	50%	50%
Proportion defecating	%	1%	1%
Estimated nitrogen load	kg-N/day	0.003	0.37
	kg-N/yr	1.13	NA

Nitrogen loads from recreational boaters are small in comparison to other nitrogen loads delivered to Budd Inlet. Recreational boaters do not likely contribute significant loads of nitrogen to Budd Inlet, even during peak summer usage. While recreational boaters should not discharge wastes other than at approved pump-out stations, the impacts are likely greater in terms of bacteria and lesser in terms of nutrients.

Potential marina loads

We used the same approach to estimate potential loads from live-aboard vessels in marinas within Budd Inlet as for recreational boaters. The screening-level estimates in Table 5 are for both annual average and summer peak usage based on per capita contributions and assumptions for the number of people, proportion of time at the marina, and proportion of people releasing wastes to marine waters.

Table 5. Estimates for potential marine wastewater discharged to Budd Inlet.

Variable	Unit	Annual Average	Peak Summer
People using Budd Inlet marinas per day	#/day	500	2000
Proportion of day at marine	% day	75%	75%
Proportion urinating overboard	%	25%	25%
Proportion defecating	%	5%	5%
Estimated nitrogen load	kg-N/day	1.2	4.6
	kg-N/year	422	NA

Nitrogen loads from live-aboard vessels in Budd Inlet marinas are small in comparison with other loads of nitrogen to Budd Inlet. Marinas do not likely contribute significant loads of nitrogen to Budd Inlet, even during peak summer usage. While live-aboard vessels should not discharge wastes other than through appropriate wastewater facilities at the marinas, the impacts are likely greater in terms of bacteria and lesser in terms of nutrients.

Shellfish for restoration

Several recent and ongoing studies evaluate the potential benefits of native and aquaculture shellfish at mitigating nutrient inputs (Konrad, 2014). One potential management action is to grow shellfish in Budd Inlet. As the shellfish are growing, they filter the water. When the shellfish are harvested, the nutrients bound in the shellfish tissue are removed from the system.

An ongoing study by the Pacific Shellfish Institute focuses on the nutrient removal potential of harvesting native Pacific blue mussels (*Mytilus trossulus*) grown on straps hung from dock structures (Rasmussen and Christy, 2013). The straps were colonized naturally and were an active part of the Budd Inlet ecosystem, including predation by crabs and sea stars. The pilot studies at four locations around Budd Inlet, from the Olympia Peninsula to Boston Harbor. PSI harvested 4300 lbs of mussels. The nitrogen content of shell and tissue material combined is 1%, which is equivalent to about 43 lbs of nitrogen removed over 120 days or 0.36 lbs/day for the pilot locations. The total potential harvest was 86% higher but not captured due to a number of factors: losses associated with processing the straps, late season drop-off, desiccation during harvest, early season mussel harvest, and overwinter predation. The study will also estimate potential nitrogen removal from larger tests in Budd Inlet since this mass removed was only equivalent to a small portion of actual dock space (Christy, 2014, personal communication). These preliminary estimates will be refined in the project report due in December 2014.

Summary of Budd Inlet scenarios

The cumulative impact of all human activities causes DO concentrations to decrease by more than 0.2 mg/L throughout most of south and central Budd Inlet compared with natural conditions without human sources and without the Capitol Lake dam. The Capitol Lake dam causes the largest single impact on DO of any activity evaluated due to the combined effects of changing circulation and altered nitrogen and carbon loads in southern Budd Inlet. Removing the dam would provide the largest improvement in seasonal minimum DO levels. Reducing external sources, decreasing loads from the LOTT outfall, and implementing strong nonpoint source reductions also would improve oxygen. Adding advanced treatment to three small wastewater treatment plants in Budd Inlet, shifting the LOTT outfall north, and reducing recreational or marina boat discharges would not improve oxygen conditions significantly.

The proportion of impacts of various scenarios are expressed as ranges because the DO impacts and nitrogen inputs are not perfectly linear (Figure 29 and Figure 30). For example, the relative benefit of eliminating local point sources (PS) depends on whether the local nonpoint sources (NP) and sources outside the Budd Inlet boundary (OBC) remain. If only the local point sources are eliminated, the net benefit is smaller than would occur if the local nonpoint sources and sources outside the Budd Inlet boundary had already been eliminated in a scenario. This occurs because reducing the high end of nutrient loads does not reduce the availability of nutrients enough to alter phytoplankton growth. However, if nutrients are more limited, then reducing nutrients even more would have a stronger influence on phytoplankton growth.

Evaluating individual scenarios is an important step in understanding the relative impacts of different existing sources. Management scenarios must consider controlling multiple sources to achieve the water quality standards. These scenarios will also account for the full oxygen benefit of combined management actions, including the nonlinear relationship between load reduction and oxygen benefit.

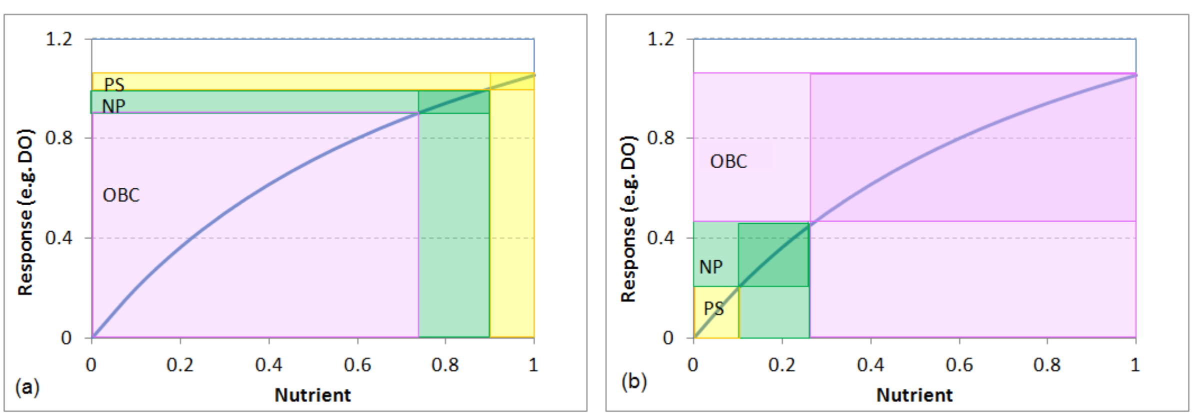


Figure 29. a) Smaller estimated response contribution to depletion of DO by point sources (PS) if they are subtracted first from the combined anthropogenic loading, and b) larger response contribution to depletion of DO by point sources (PS) if they are subtracted last from the combined anthropogenic loading.

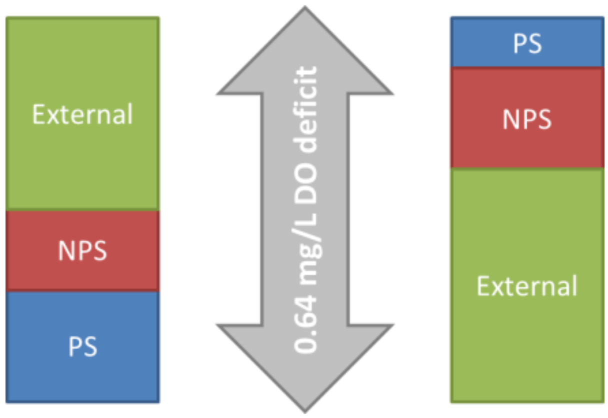


Figure 30. The estimated DO depletion due to each source depends on which order it is either added to or subtracted from other sources because DO depletion is not linearly related to loading. *For example, if the DO depletion due to combined loading from external anthropogenic sources, local nonpoint sources (NPS), and local point sources (PS) is 0.64 mg/L, the estimated contribution of each source to the total 0.64 mg/L will be different depending on the order that each source is added to or subtracted from the others*.

Figure 31 evaluates the relative contributions to maximum oxygen impact in East Bay. The relative proportions are likely similar in other regions of southern Budd Inlet; however, the overall magnitudes differ by location. The Capitol Lake dam accounts for approximately 2 mg/L deficit of the total deficit of 3 mg/L at this location. Among the remaining human nutrient sources, sources external to Budd Inlet decrease minimum oxygen by 0.3 to 0.4 mg/L. The magnitude of impact depends on whether other human sources are also eliminated, as described by Figure 29. The local sources within Budd Inlet include both point source discharges to marine waters, which decrease minimum oxygen by 0.1 to 0.2 mg/L, and nonpoint sources within the watersheds, which also decrease oxygen by 0.1 to 0.2 mg/L, depending on whether other nutrient sources are eliminated.

Point and nonpoint sources discharging to Budd Inlet decrease minimum oxygen by >0.2 mg/L in this critical East Bay region, which violates the water quality standards. Local sources together with sources outside of Budd Inlet decrease minimum oxygen by 0.6 mg/L. Also considering the effect of the Capitol Lake dam, human activities decrease minimum oxygen levels in East Bay by as much as 3 mg/L.

The non-linearity of impact of load reductions on DO depletions is also applicable to the impact of dam removal. For example if we compare the existing condition with dam in place to natural estuarine conditions, the maximum depletion in the critical East Bay cell is about 3 mg/L. If we compare existing conditions with no dam to natural estuarine conditions, we get a DO depletion of 0.64 mg/L. The difference is approximately 2.4 mg/L, which is due to the dam itself. However, if we compare natural loading conditions with the dam in place to natural estuarine loading conditions, the DO depletion is approximately 2 mg/L. Although the numbers are of same order of magnitude, small but significant difference exists between the two. Circulation and nutrient loading separately affect DO, but together they can produce synergistic effects that add up to more than the sum of the individual impacts. Another factor that may play a role is that the sediment fluxes in the Capitol Lake region under natural estuarine conditions is the same as the inner Budd Inlet, where as those under the natural condition with dam in place reflect freshwater lake sediment fluxes.

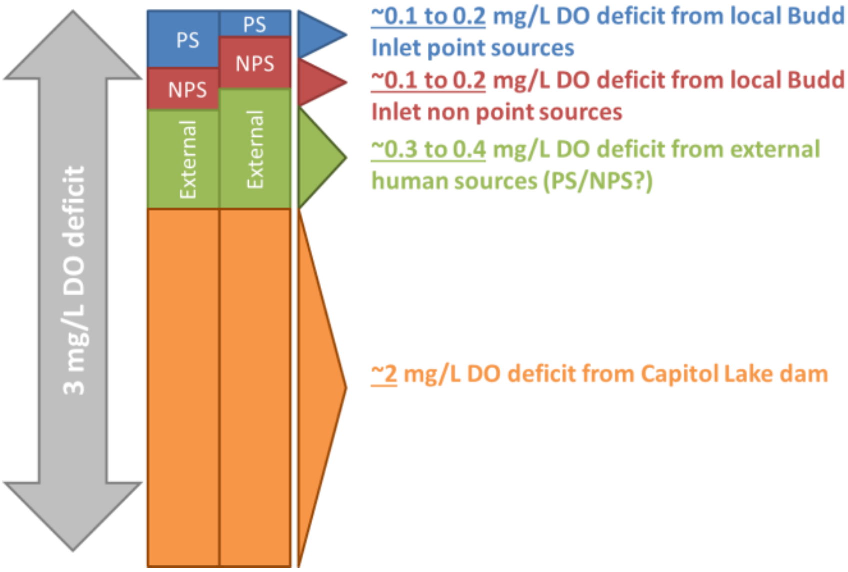


Figure 31. The estimated range of contributions to DO depletion at the critical cell in East Bay from various anthropogenic sources due to various alternatives for the order of addition to or subtraction from other sources.

The dam itself causes changes to circulation in southern Budd Inlet as well as changes in carbon and nitrogen loading. The combined effect of these three factors worsens oxygen throughout southern Budd Inlet. However, the remaining scenarios generally focus on reducing nitrogen loads to Budd Inlet. The oxygen benefit scales with the magnitude of the load reduction (Figure 32). The larger the load reduction, the larger the oxygen benefit of a particular management action.

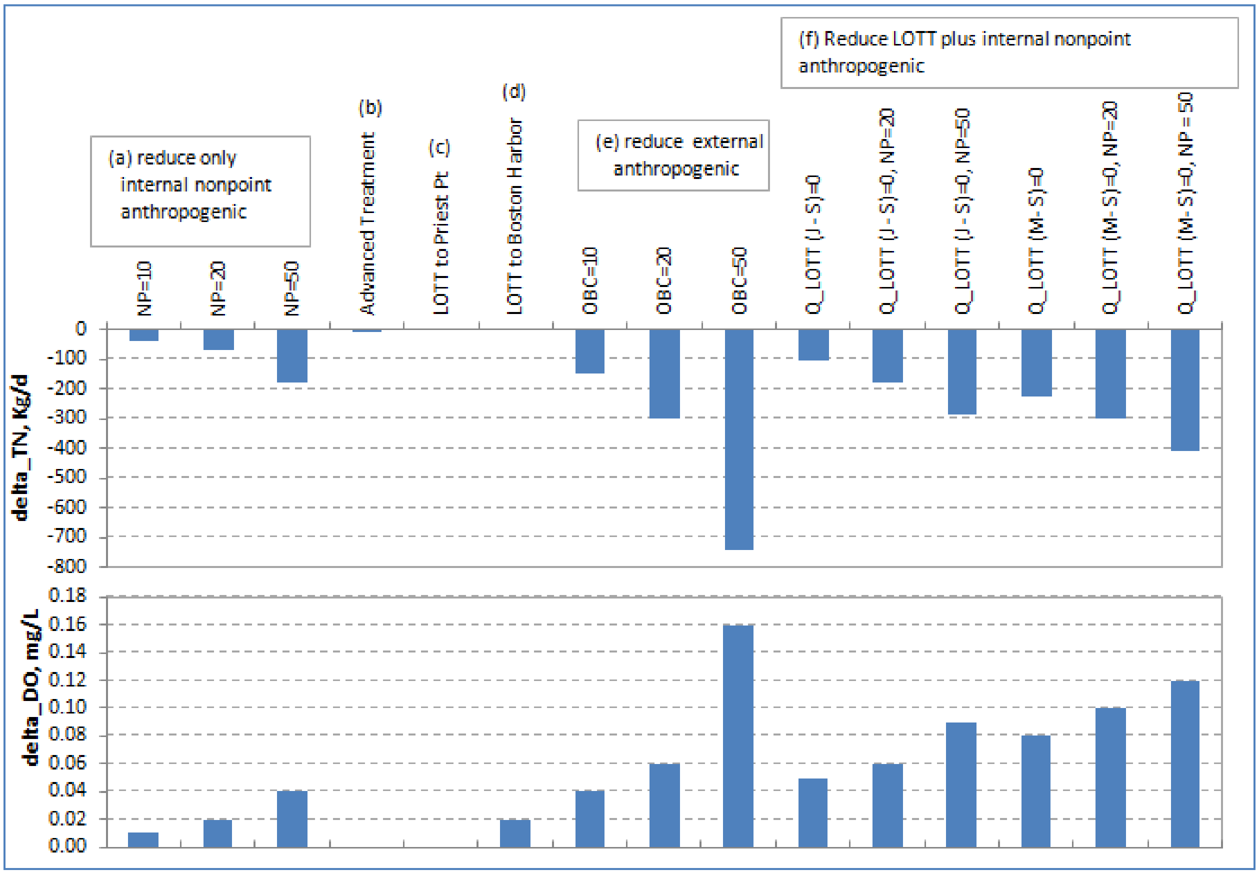


Figure 32. The estimated nitrogen loading reduction and DO improvement at the critical East Bay cell for the various model scenarios including a) reduction of local nonpoint anthropogenic load by 10%, 20%, or 50%, b) advanced treatment by local small WWTPs, c) moving the LOTT outfall to north of Priest Point, d) moving the LOTT outfall to Boston Harbor, e) reducing external anthropogenic loading by 10%, 20%, or 50%, and f) reducing LOTT and local nonpoint anthropogenic loading.

Oxygen impacts are evaluated within each layer of each grid cell used to describe Budd Inlet using the computer model. Figure 33 provides an example of the calculations in a single layer of a single grid cell across three different scenarios. The daily minimum concentration in the bottom layer of the critical location of East Bay reflects seasonal, tidal cycle, and even smaller-scale phenomena. The blue line represents the daily minimum DO concentration with the current human activities (Capitol Lake dam in placed and both local and external human sources contributing). DO follows complex patterns in time. DO levels reach a seasonal maximum in spring then decline through summer and fall. Within those seasonal cycles, the neap-spring tidal cycle causes increases and decreases in oxygen due to shifts in circulation and faster or slower flushing.

Eliminating the human sources (local point sources, local nonpoint sources, and external human sources) would increase the minimum oxygen levels in the bottom layer of the East Bay cell (red line). The magnitude varies slightly over the year, but the biggest difference between the blue and red lines occurs later in the year. The green line represents the natural condition for this location – no dam and no human nutrient sources affecting Budd Inlet. Even under natural conditions, the minimum oxygen levels display seasonal, tidal cycle, and smaller-scale variability. However, the minimum oxygen levels would be higher than would occur with the dam in place throughout the year.

Figure 33 and Figure 15 show that the predicted depletion of DO is persistent across several months and relatively large compared with the model skill. The predicted depletion of DO at the critical location in East Bay and in most other locations is statistically significant because the predicted DO for various model scenarios are highly correlated with each other. In other words when predicted DO is low or high in one scenario it is also low or high at the same time in the natural conditions scenario or any other scenario. Practically all of the predicted DO violations for estuary alternatives are statistically significant (greater than twice the estimated RMSE of differences).

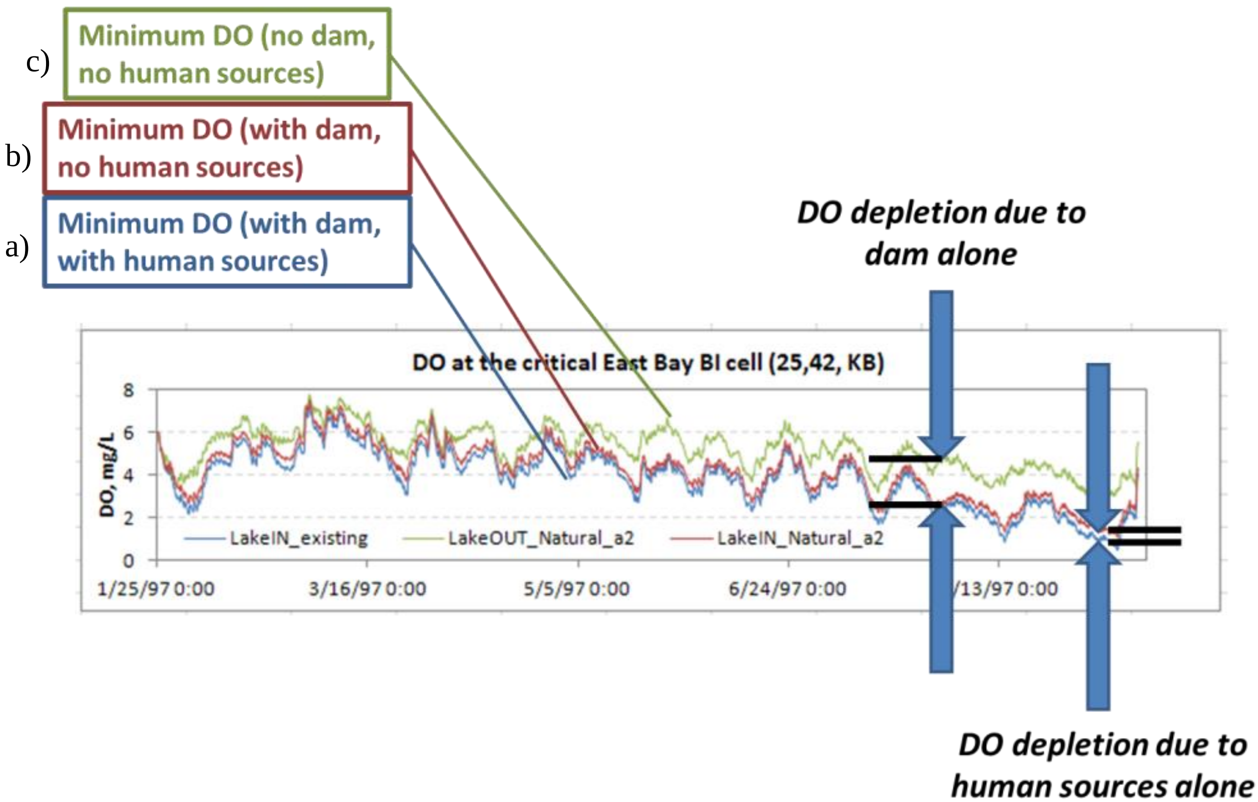


Figure 33. DO in the bottom layer at the critical cell in East Bay a) at the existing condition with the Capitol Lake dam and current anthropogenic sources, b) with the Capitol Lake dam and no anthropogenic sources, and c) without the Capitol Lake dam and without anthropogenic sources.

Additional scenarios identified but not analyzed

The September 2011 and February 2012 advisory group meetings identified several other scenarios related to Budd Inlet that were considered but were prioritized lower than the scenarios evaluated or could not be evaluated quantitatively. These are described qualitatively below.

Install aerators in Budd Inlet

Theoretically, installing aerators in portions of Budd Inlet could increase DO by mechanical action. This would have required modifications to the water quality model of Budd Inlet that were beyond the resources available. We considered simply adding a tributary with very low flow but high oxygen concentration to provide a screening-level estimates. The scenario was not pursued further.

Shift from marine wastewater discharge to groundwater discharge

Moving the LOTT outfall from a marine discharge location to a groundwater discharge location upstream in the watershed could not be evaluated with existing tools. The nitrogen load from the groundwater discharge would need to be modeled through groundwater and surface water pathways to consider the attenuated load to Budd Inlet. It is not realistic to simply eliminate the LOTT outfall and neglect nitrogen redirected to other locations. Nitrogen travels in dissolved form and undergoes complex transformations that are highly variable in space and time. This topic was deferred to the ongoing LOTT groundwater study (LOTT, undated). The scenario was not pursued further.

Establish no-discharge zone

This scenario was suggested to decrease nutrients introduced directly to marine waters. Ecology is separately pursuing a no-discharge zone through other regulatory pathways primarily to reduce pathogen impacts. Ecology instead conducted the screening-level analysis of potential impacts of nitrogen from boater waste. The scenario was not pursued further.

Scenarios with potential benefits but no quantitative information

The advisory group identified a number of scenarios that have been linked theoretically to water quality benefits in Budd Inlet through existing literature. However, no local data exists to support the quantification of this benefit. The following activities could be considered in the WQIR:

- Reduce effective impervious cover
- Reduce residential, commercial, and institutional fertilizer use
- Reduce pet waste
- Increase urban tree canopy
- Decrease roof runoff
- Fix cross-connections between sanitary and stormwater systems
- Install rain gardens

Potential implementation tools

The advisory group also identified several practices that could be considered for implementation of scenarios. The following actions could be considered in the WQIR:

- Nutrient trading
- Public education
- Statewide ban on phosphorus in detergents and some fertilizers (in effect now but could estimate the benefits if needed)

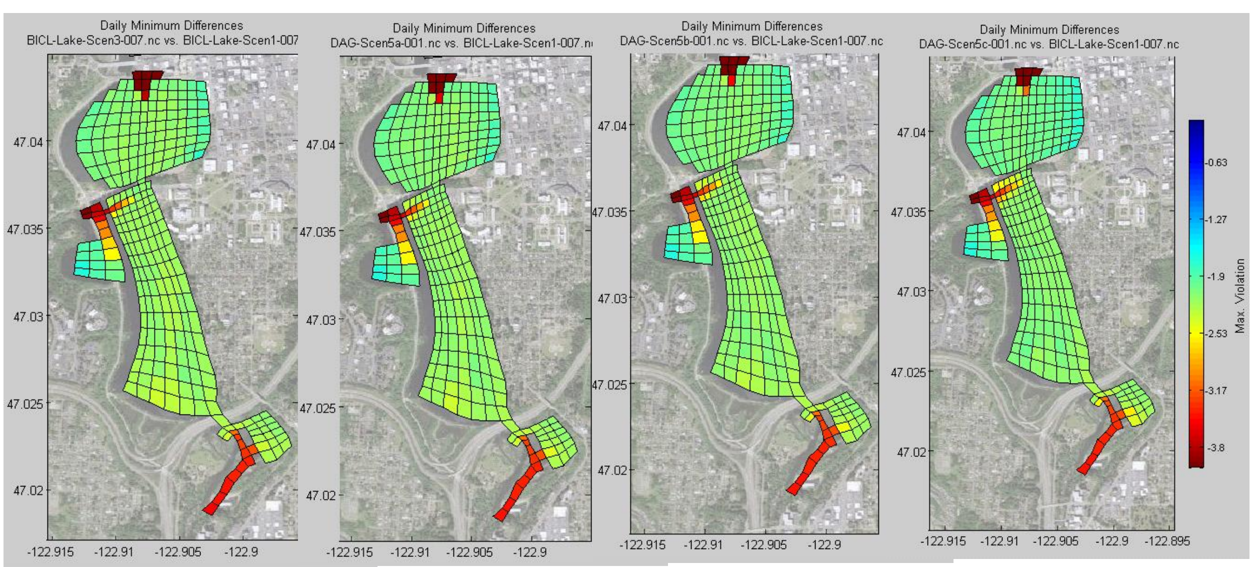
Capitol Lake Scenarios

We evaluated potential management activity benefits on water quality in Capitol Lake through a combination of computer modeling and other analyses. These included both improvements from the watershed and in-lake activities.

Reduce nonpoint phosphorus loading

We evaluated the potential benefit of nonpoint source reduction programs on DO in Capitol Lake. The scenario compared oxygen under existing loading with oxygen resulting from reducing the anthropogenic river contributions by 10, 20, and 50%. The river contributions still included natural sources as described in Appendix I of Roberts et al. (2012). The predicted response of DO depletion to various amounts of reduction of non-point phosphorus load is presented in Figure 34. DO depletion is not predicted to be sensitive to reduction in non-point phosphorus load in the range of 10% to 50% reduction.

Even moderately successful nonpoint source reduction programs would not alter primary productivity in Capitol Lake. Natural sources of phosphorus would still deliver ample phosphorus to drive plant growth. Rooted plants would still access phosphorus in the sediments, even if water column phosphorus concentrations decline.



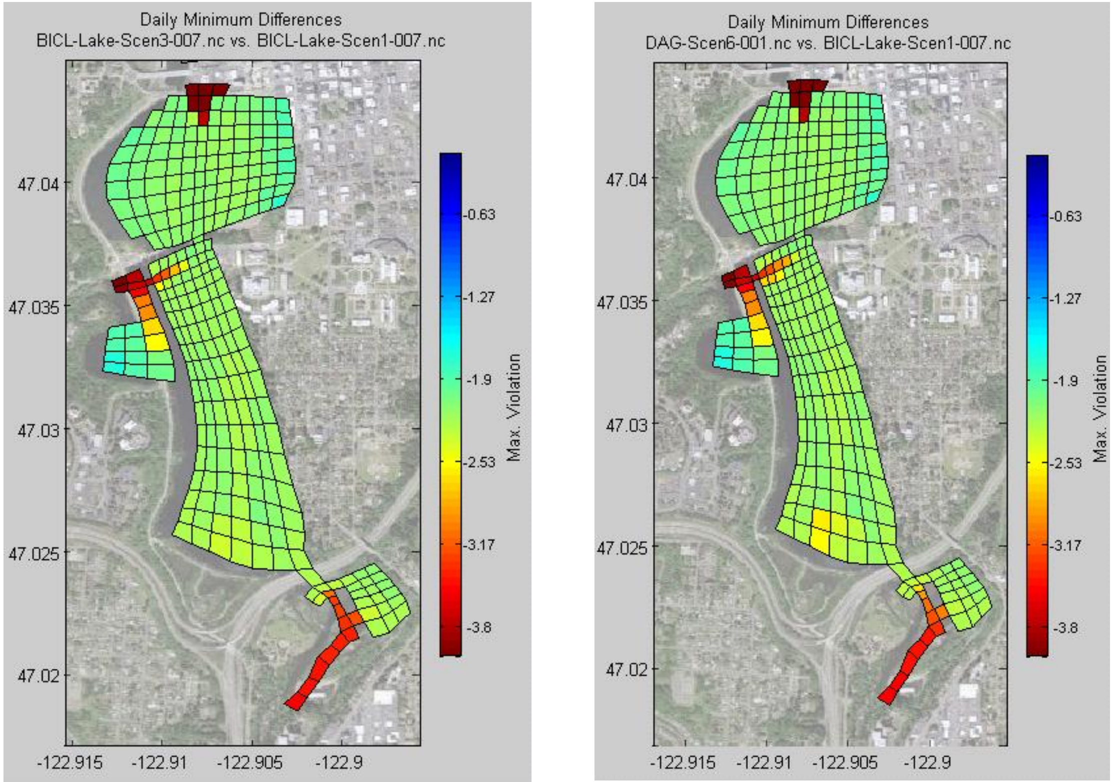
Existing vs natural **10% NP_P reduction vs. Ntural** **20% NP_P reduction vs. Existing** **50% NP_P reduction vs. Existing**

Figure 34. Predicted DO depletion (mg/L) from various assumed reductions in nonpoint P loading to Capitol Lake.

Reduce temperature of the Deschutes River

A question originally posed by the predecessor agency to DES was whether the temperature benefits of improved riparian vegetation would improve oxygen conditions within Capitol Lake. Cooler water holds more oxygen. The water temperature modeling for the Deschutes River showed that the current water temperatures are elevated about 4 degrees C above natural conditions. We evaluated the potential of improving riparian vegetation to improve oxygen in Capitol Lake by decreasing the temperature of the Deschutes River inflow to the natural conditions predicted by the Deschutes River temperature model and increasing the oxygen to reflect the cooler temperature.

The predicted response of DO depletion to decreases in the water temperature to natural temperatures in the Deschutes River is presented in Figure xx. Decreasing the water temperature during the warm summer months would not alter DO patterns appreciably in Capitol Lake. Only the south basin, where the Deschutes River flows from the falls, shows improvements, and those are very minor in magnitude and extent. The temperature of the north and middle basins of Capitol Lake is dominated by solar radiation on the lake surface and not by the temperature of the Deschutes River inflow. Overall, the predicted DO depletion in Capitol Lake is not sensitive to reduction of about 4 degrees C in the water temperature in the Deschutes River. While riparian vegetation is very important to cooling the Deschutes River for the benefit of upstream freshwater aquatic life, this management scenario would not translate to benefits within Capitol Lake.



Existing vs natural **Low temp input vs. Natural**

Figure 35. Predicted DO depletion (mg/L) in Capitol Lake with decreased water temperature in the Deschutes River.

Alum treatment to reduce phosphorus in Capitol Lake

Alum is a coagulant that binds organic matter so that it settles to the sediment. Adding alum to lakes can clear the water column of both dissolved and particulate phosphorus as well as algae. Alum treatments trap the phosphorus in the sediments temporarily, which reduces the water column phosphorus available for plant growth. To simulate this scenario, we set the initial concentration of orthophosphorus, particulate organic phosphorus, and algae to zero within the lake and reduced sediment fluxes by 20, 50, and 75%. The Deschutes River and Percival Creek continued to provide phosphorus loads from the watershed, and primarily from natural sources. We compared the oxygen levels following an alum treatment with current conditions.

Figure xx shows that violations and seasonal oxygen patterns would not change. The watershed inputs would continue to provide ample phosphorus. Because the flushing time for Capitol Lake is so fast, the watershed contributions would quickly reset the water column conditions to pre-application concentrations. Furthermore, plant growth includes both phytoplankton and nutrients. Water column phosphorus changes could affect phytoplankton but would likely have little effect on macrophytes, which derive nutrients from root systems in the sediments. The alum treatment would not decrease phosphorus available for macrophytes, and the short-term water column benefit would not have a seasonal benefit from controlling phytoplankton. Capitol Lake would still violate the lake DO standards after an alum treatment.

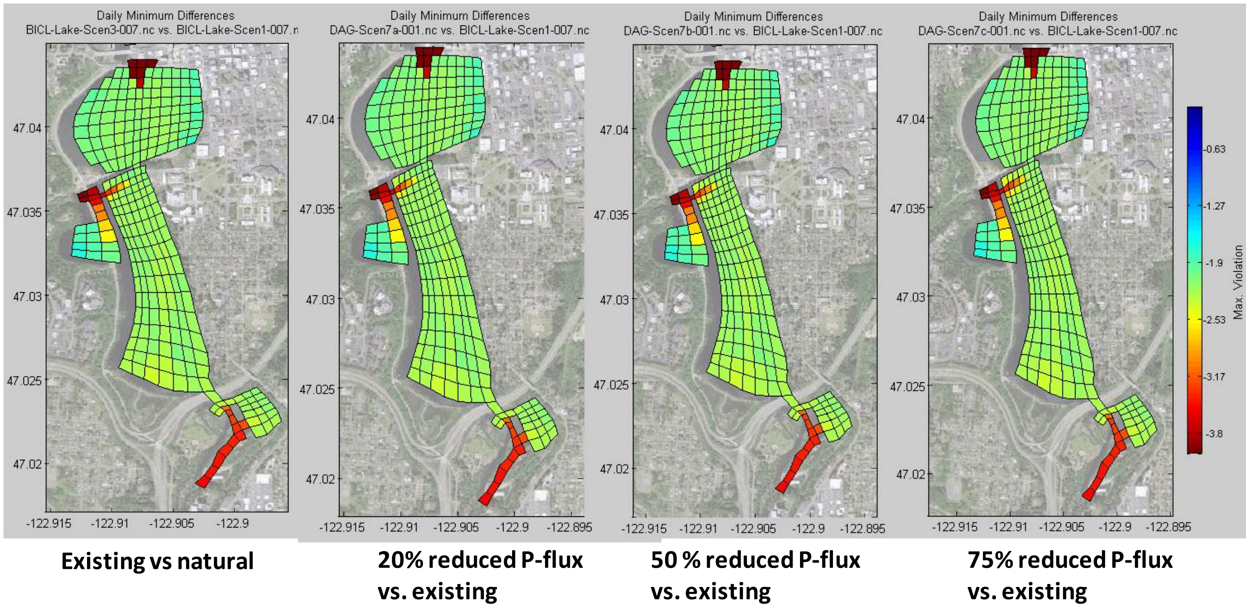


Figure 36. Predicted DO depletion (mg/L) in Capitol Lake with reduced sediment/water flux of P.

Dredge Capitol Lake to nominal 13 ft depth

General Administration, currently the Department of Enterprise Services, is responsible for the management and operation of Capitol Lake since its construction in 1951. Previously GA dredged the lake and backflushed it with salt water from Budd Inlet to control the plant growth in the lake. However, these practices were discontinued after 1986 due to environmental concerns. GA developed and the State Capitol Committee approved the Capitol Lake Adaptive Management Plan (CLAMP) 2003-2013 to guide the oversight of the lake. The CLAMP Steering Committee evaluated a rage of alternatives for managing the lake including dredging the lake, removing the dam, a dual-basin, and status quo, which would result in a freshwater marsh.

One of the CLAMP objectives was to manage water quality, and the steering committee relied on Ecology's ongoing water cleanup plan for technical support. Another objective included the Deschutes Estuary Feasibility Study. The steering committee also relied on Ecology's analyses to understand relative influences on water quality for this alternative.

While Ecology's technical report included assessments of water quality in the existing lake and potential estuary, Roberts et al. (2012) did not evaluate the dredged-lake alternative quantitatively. GA requested analyses of water quality under the managed lake alternative (Jones, 2008) in a letter that posed three questions:

1. If Capitol Lake were to be managed as a lake with routine dredging of a nominally uniform thirteen feet, how would this affect the five TMDL water quality factors for the lake and for Budd Inlet?
2. If the upland shading improvements proposed in the water quality study findings were implemented, how would this affect the five TMDL water quality factors for the lake and for Budd Inlet?
3. And finally, what would be the effect of implementing both the shading improvements and the lake dredging on the lake and on Budd Inlet relative to the five TMDL water quality factors?

Responses were included in a letter from Ecology (Roberts, 2009). In 2009, Ecology did not have the resources to pursue additional model runs to respond to questions 2 and 3. However, the Deschutes Advisory Group requested subsequent model-based analyses to characterize improvements, and these are described above. The following sections summarize the analyses presented in response to the first question – whether or not dredging to 13 ft on average would improve water quality in Capitol Lake.

The managed lake alternative would rely on routine dredging to maintain the lake at a nominal 13 ft (4.0 m) water depth. This depth is below the summer setpoint elevation of 6.22 ft NGVD29 or 14.31 ft MLLW, as clarified by General Administration (January 28, 2009 email). Portions of the north basin are somewhat deeper and would not change. A 100-ft buffer near the shoreline would remain undisturbed. Following dredging, the sediments would be expected to achieve a natural angle of repose.

Table 6 includes the lake geometry available in 2009 per General Administration (February 4, 2009 email). The overall average lake depth determined from total lake volume and surface area was 10.4 ft in 2009. We estimated dredged lake volumes by assuming the nominal 13 ft water depth was equivalent to the average depth presented for the entire lake. This results in no change to the north basin value because the current mean depth is given as 13 ft. The assumption likely underestimates the north basin volume under a dredged lake. The assumption likely overestimates the volume of the middle, south, and Percival basins because it applies the mean depth to the entire surface area of all three basins. Only nominal changes to bathymetry in the south basin and Percival would be included, and a 100-foot buffer (approximately 15% of the total surface area) would remain unchanged. The resulting dredged lake estimates represent the best available values.

Table 6. Capitol Lake characteristics for 2009 existing conditions and under a dredged lake alternative.

Parameter		2009 Lake Conditions	Dredged Lake Conditions	Relative Change (%)	Source
		Geometry			
A	Surface area (ac)	261	261	0%	GA
A	Surface area (ft^2)	11,369,160	11,369,160	0%	calculation
A	Surface area (m^2)	1,056,230	1,056,230	0%	calculation
V	Volume (ft^3)	118,637,000	147,799,080	22%	GA
V	Volume (m^3)	3,359,426	4,185,204	22%	calculation
d	Mean depth (ft)	10.4	13.0	22%	GA, ECY assumption
d	Mean depth (m)	3.2	4.0	22%	calculation
		River Inflows			
$Q_{mean,1991-2007}$	Deschutes (1991-2007 annual mean, cfs)	396	396	0%	USGS data, ECY calculation
$Q_{mean,1991-2007}$	Deschutes (1991-2007 annual mean, cms)	11.2	11.2	0%	USGS data, ECY calculation
$30Q10_{1991-2001}$	Deschutes (1991-2001 30Q10, cfs)	59.8	59.8	0%	USGS calc
$Q_{Sept,1945-2007}$	Deschutes September mean (1945-2007, cfs)	97	97	0%	USGS data, ECY calculation
	Deschutes late-summer flow (9/28/04, cfs)	113	113	0%	USGS data
	Deschutes late-summer total phosphorus (9/28/04, mg/L)	0.0202	0.0202	0%	ECY data
		Residence Time			
$T_{res,annual}$	Mean Annual (Vol/Qmean, days)	3.5	4.3	22%	calculation
$T_{res,summer}$	Summer Critical (Vol/30Q10, days)	23.0	28.6	22%	calculation
$T_{res,summer}$	Late summer Critical (Vol/$Q_{09/28/04}$, days)	12.2	15.1	22%	calculation
		Phosphorus Loading Rates			
	Annual TP Deschutes* (1996-97, kg/d)	75	75	0%	calculation
	Annual Areal Loading Rate, river only ($g/m^2/yr$)	25.9	25.9	0%	calculation
	TP Deschutes 9/28/04 (kg/d)	5.6	5.6	0%	calculation
	9/28/04 Areas Loading Rate, river only ($g/m^2/yr$)	1.9	1.9	0%	calculation
	Model TP sediment flux** (kg/d)	4.7	4.7	0%	calculation
	Model TP sediment flux** ($g/m^2/yr$)	1.6	1.6	0%	calculation
	Max TP sediment flux *** (kg/d)	30.6	30.6	0%	calculation
	Max TP sediment flux *** ($g/m^2/yr$)	10.6	10.6	0%	calculation
		Vollenweider Coefficient			
$d/Q_{mean,1991-2007}$	Depth/Mean annual residence time (m/yr)	334	340	0%	calculation

Notes * Includes Percival Creek watershed
** Used for Capitol Lake model
*** Based on highest rate measured in late summer 2004

The table also summarizes geometry for the dredged lake based on the assumptions described above. Only the Deschutes River inflows are included because long-term gaging data for Percival Creek were not available and would not change the overall findings described below. Both annual mean and summer low-flow values are provided for context. Residence time is calculated for both the annual average discharge and the summer low flow discharge.

Phosphorus loading rates and other derived coefficients are presented based on data collected in the water cleanup study as well as previous efforts. Data collected September 28, 2004 provide an indication of late-summer conditions on one particular date. The date itself is not meaningful, only that it provides summer context to compare with annual average values. The summer river loads normalized by the lake surface area are equivalent to 1.9 g/m2/yr of phosphorus.

Annual phosphorus loads were developed in a previous study that included the Deschutes River. Albertson et al. (2002). Roberts and Pelletier (2001) describe the statistical method used to estimate annual loading rates from monthly monitoring data and flow gaging. The annual areal loading rate developed for 1996-97 (wetter-than-average conditions) was equivalent to 25.9 g/m2/yr. The value is much higher than summer loads because the flows are much higher in the winter months and most of the sediment transport occurs in the winter; phosphorus tends to associate with sediment particles.

Areal loading rates provide an indication of the trophic state of lakes. Generally, the higher the loading rate, the more eutrophic the system. Vollenweider (1968) summarized depth and loading rate information for a large number of lakes into a graphic of trophic state to produce a planning-level tool for lake managers.

Figure xx identifies the lake trophic state as a function of the areal phosphorus loading rates and the depth. The trophic state refers to the level of biological activity. Eutrophic lakes are characterized by high plant growth (suspended or rooted) and poor water clarity. Oligotrophic lakes clear with low nutrient concentrations. Mesotrophic lakes are in the middle of this continuum. The graphics can be used to understand the influence of alternative depths or loading rates on the lake trophic status.

The current (2009) annual phosphorus areal loading rate and depth confirm that Capitol Lake is highly eutrophic, and actually falls above the maximum phosphorus loading rate in the Vollenweider (1968) graphic. Capitol Lake has had excess plant growth for many years and very low water clarity.

Dredging the lake to an average 13 ft would shift Capitol Lake to the right, but the areal phosphorus loading rate would still be off the chart. Capitol Lake would remain highly eutrophic, with excess plant growth and poor water quality expected. The lake would need to be dredged to over 100 m to shift into the mesotrophic range, which is not likely feasible with the current geometry and location at the south end of Budd Inlet.

With or without dredging to 13 ft, the annual areal phosphorus loading rate would need to be reduced to 0.1 to 10% of the current values to achieve the mesotrophic range. However, natural sources contribute phosphorus such that reducing to 0.1 or 10% of current values is not feasible. Natural sources alone would cause eutrophic conditions in a shallow lake such as Capitol Lake.

Even if all human and natural sources of phosphorus were eliminated from the watershed, the sediment fluxes alone would provide ample phosphorus to maintain eutrophic conditions in Capitol Lake.

Vollenweider's areal loading analyses were based on annual loads from the watershed. However, total phosphorus fluxes from the sediments also are significant. Sediment fluxes vary over time, but the highest fluxes often coincide with warm temperatures and high pH values within the lake. The mean nutrient flux used in the Capitol Lake model is 1.6 g/m2/yr, which is well into the eutrophic range for all but the deepest lakes. Considering residence time (Figure xx), sediment fluxes alone (1.6 g/m2/yr and 334 m/yr) would plot in the middle of the mesotrophic range, even if the watershed produced zero phosphorus loading. This is not feasible, since the Deschutes River watershed delivers phosphorus from natural sources. The combined sediment and watershed nutrient fluxes plot in the eutrophic range.

Even if the watershed sources decrease substantially, sediment fluxes are likely to continue contributing significant phosphorus loads. No information currently available suggests that the underlying sediments that may be revealed by dredging would increase or decrease the sediment fluxes. Algae blooms that raise the pH of Capitol Lake could produce maximum sediment fluxes that are at least six times higher than the mean value used in modeling.

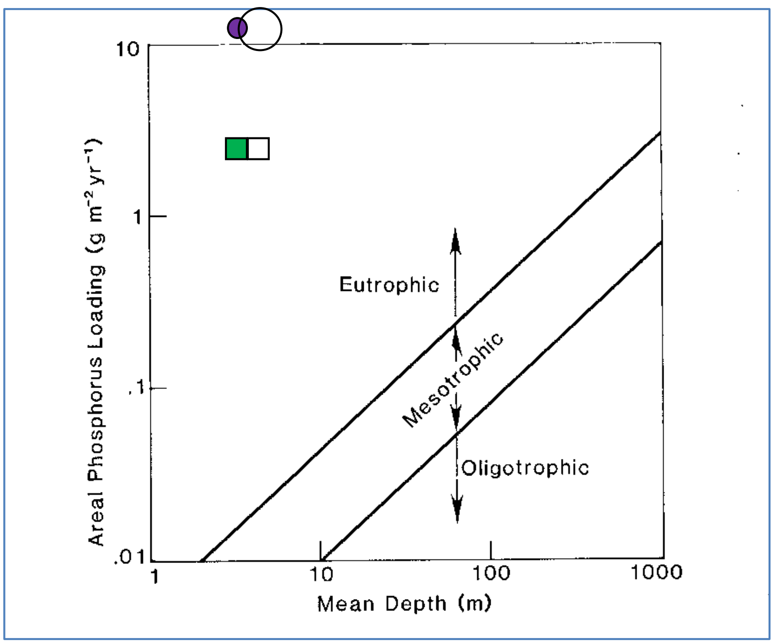


Figure 37. Vollenweider's (1968) phosphorus loading plot showing areal loading vs. mean depth, with the expected trophic state.

The circles represent annual values for the current conditions (solid circle) and the dredged lake alternative (open circle). The squares represent the summer current (solid square) and dredged lake (open square) conditions. Source: Reckhow and Chapra (1983).

Vollenweider (1975) revised the earlier analysis to account for differences in residence times of lakes. The y-axis in Figure xx is the same as above for annual areal phosphorus loading rate, but the x-axis is modified to normalize depth by residence time. Under current (2009) conditions, this updated graphic still indicates that Capitol Lake is highly eutrophic and also plots above the maximum phosphorus loading rate on the chart. Because the depth increase associated with the managed lake would produce an offset in residence time, the only shift occurs due to rounding values in the calculations for the second figure.

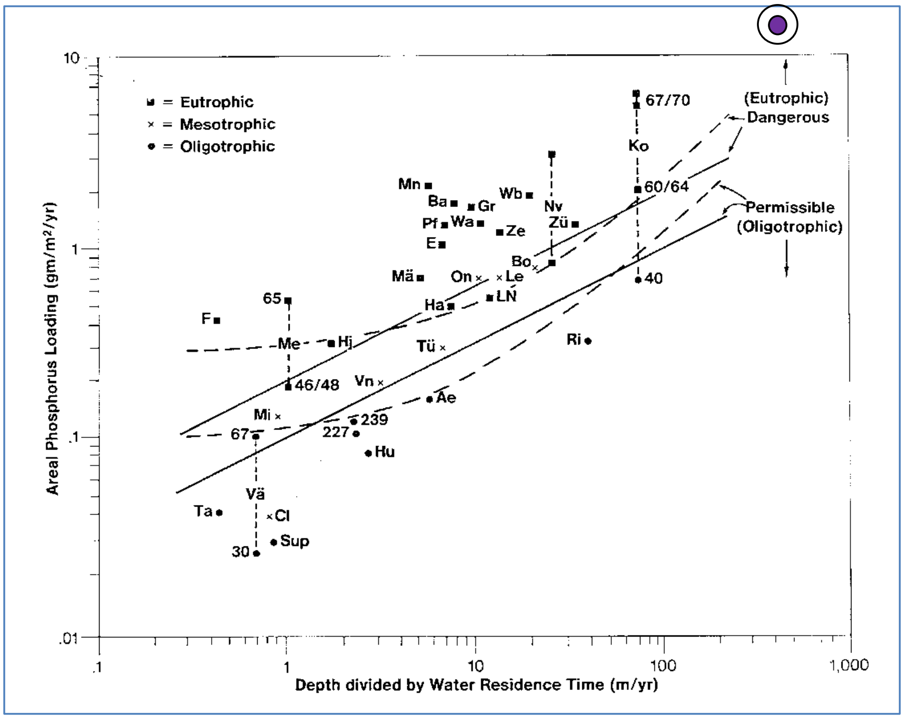


Figure 38. Vollenweider's (1975) phosphorus loading plot to include the residence time with trophic state.

The solid circle represents annual values for current conditions and the open circle represents the dredged lake alternative. Letters identify specific lakes described in the source publication: Reckhow and Chapra (1983).

Capitol Lake is highly eutrophic based on the Vollenweider graphics and would remain eutrophic even if the lake were dredged or human phosphorus sources were eliminated. Ongoing monitoring by Thurston County (Davis, 2008) indicates that the north basin is eutrophic (Carlson Trophic State Index using chlorophyll and phosphorus). The middle basin is eutrophic to mesotrophic. Because the depth changes are relatively small relative to current conditions under the dredged lake alternative (22% increase), we do not expect significant changes in water quality and related parameters.

Two forms of plants affect Capitol Lake. Phytoplankton are floating plants that derive their nutrients from the water itself. Macrophytes are rooted plants that derive their nutrients from both the sediment and the water; the ratio varies with the plant species. Phytoplankton and macrophytes compete for nutrients and light. Even if water column nutrients were reduced, the shallow lake depth would allow macrophytes that derive nutrients from the sediments to grow. The lake would need to be dredged much deeper than 13 ft to reduce light availability to rooted macrophytes. Because of the angle of repose of lake sediments, deeper dredging would still leave a ring of shallower water where macrophytes could thrive.

In summary, dredging the lake to a nominal 13 ft depth would not produce measurable or visual improvements in water quality within the lake. Even combined with elimination of human sources from the Deschutes River watershed, dredging would not improve lake water quality. Because dredging and/or watershed reductions would not change the lake conditions, the impacts of the lake on Budd Inlet also would not change. Dredging, even when coupled with elimination of human nutrient sources from the Deschutes River watershed, would not decrease the oxygen impacts on Budd Inlet.

Eliminate stormwater outfalls to Capitol Lake

The study design did not include detailed nutrient loads from the urban areas around Capitol Lake not captured in estimates for the Deschutes River or Percival Creek. We developed load estimates for the Deschutes River and Percival Creek based on measured monthly phosphorus concentrations and daily flows. For the 1996-97 simulation period, the Deschutes River average flows were 550 ft^3/s, while Percival Creek flows were estimated as 90 ft^3/s. Ecology's ambient monitoring data for the Deschutes averaged 0.047 mg/L for 1996-97 but were 0.025 for 2013 total phosphorus concentrations. Percival Creek monitoring conducted as part of the TMDL indicated average phosphorus concentrations of 0.027 mg/L. These two inflows deliver approximately 63 and 5.2 kg/d, respectively.

Contributions for the urban area surrounding Capitol Lake were estimated from annual runoff volumes and two sources for phosphorus in stormwater monitoring. Herrera (2011) monitored phosphorus and hundreds of other parameters in small watersheds with four characteristic land cover types. We assumed stormwater monitoring for commercial watersheds was most appropriate to characterize urban areas around Capitol Lake. The watershed sizes ranged from 530 to 1600 acres in Herrera (2011), comparable to the 1330 acres that drain to Capitol Lake directly. In addition, City of Tumwater monitors a variety of parameters in stormwater within stormwater infrastructure. We used the median value from 2001 and 2010 monitoring to indicate water quality for the urban runoff surrounding Capitol Lake.

Table 7 presents the estimates. The urban areas surrounding Capitol Lake deliver 0.4 to 4.4 kg-P/day to the lake. The total input from the Deschutes River, Percival Creek, and the urban areas surrounding the lake total 73.6 kg/d as an annual average, using the higher value for urban inputs. Therefore, runoff from urban areas represents up to 6% of the total annual phosphorus load to Capitol Lake although it is 1% of the area draining to Capitol Lake.

Stormwater controls are an essential part of management programs throughout the Puget Sound region, and programs are in place to reduce these sources to achieve multiple benefits. However, eliminating 4.4 kg/d would not affect the eutrophic conditions in Capitol Lake based on the Vollenweider analyses. Capitol Lake water quality would not measurably or visually improve.

Table 7. Estimates of Capitol Lake urban contributions beyond Deschutes River or Percival Creek watersheds

Variable	Value	Unit	Source
Area	1330	ac	GIS
Precipitation (Olympia Airport)	56.6	in/yr	www.co.thurston.wa.us/monitoring/noaa/noaa-historical.html
Evapotranspiration	15	in/yr	Estimate
Runoff	41.6	in/yr	Calculation
	6.4	ft3/s	Calculation
Median phosphorus content in stormwater runoff from commercial lands	0.044	mg/L	Herrera, 2011
Median phosphorus content in stormwater from City of Tumwater	0.284	mg/L	Dan Smith, personal communication, 2011
Estimated phosphorus load based on Herrera (2011)	0.4	kg-P/d	Calculation
Estimated phosphorus load based on City of Tumwater data	4.4	kg-P/d	Calculation

Summary of Capitol Lake scenarios

Human contributions cause oxygen concentrations to change in Capitol Lake by more than 0.2 mg/L. Strong stormwater and other nonpoint source reductions would reduce loads. However, water quality would not improve significantly because natural sources would continue to provide phosphorus from the watershed and lake sediments would continue to fuel plant growth in the lake. Reducing Deschutes River temperature, conducting alum treatments in the lake, eliminating stormwater sources, and dredging the lake to a nominal 13 ft average depth would not improve water quality in Capitol Lake significantly.

As summarized for the Budd Inlet scenarios, model skill does not limit the applicability of the water quality model to the scenarios described above. Most of the violations for lake alternatives are greater than the overall RMSE of 0.41 mg/L for the predicted differences.

Additional scenarios Identified but not analyzed

The September 2011 and February 2012 advisory group meetings identified several additional scenarios related to Capitol Lake that were included within the scenarios evaluated but either prioritized lower than other scenarios or could not be evaluated quantitatively. These are described qualitatively below.

Solar-powered aeration system

Similar to the scenario proposed for the marine waters of Budd Inlet, this scenario was proposed to increase oxygen in Capitol Lake through mechanical action, possibly powered by solar panels. Adding oxygen would not decrease the macrophyte growth in the lake. An aerator could benefit the deep hole behind the dam to reduce phosphorus release from sediments. However, an aerator would not affect phosphorus release in other parts of the lake and would have no effect on macrophyte growth overall. This scenario was not pursued further.

Back-flush lake

This scenario was proposed based on historical practices where back-flushing the lake with salt water decreased plant (macrophyte) organic matter due to salt toxicity. The Budd Inlet Scientific Study found that back-flushing had a detrimental effect on Budd Inlet (Aura Nova Consultants et al., 1998), and the practice was discontinued. Back-flushing for New Zealand mud snail control has been part of an initial emergency control strategy and not viewed as a tool for the routine management of invasive species (*add citation from Perry*). DES views back-flushing with marine water as a potential tool for reducing the spread of the snails that would only be undertaken following thorough coordination with our natural resource partners. There is no current plan for back-flushing. Further, because back-flushing is not viewed as a routine action, this management tool need not be included in TMDL-related modeling. Historically back-flushing was not allowed to protect the freshwater mitigation site in the central basin. This scenario was not pursued further.

Harvest lake macrophytes

The intent of this scenario is to reduce plant organic matter in the lake by removing macrophytes and disposing of them off site. Monitoring conducted as part of the 2004 herbicide application to reduce milfoil indicated an average macrophyte biomass of 65.3 g/m^2 dry weight before the application (Appendix C in Roberts et al., 2012). Based on a surface area of 261 acres, this is equivalent to a plant mass of 69,000 kg, equivalent to 152,000 lbs or 76 tons dry weight. The wet weight would be substantially higher.

Two months following the herbicide application, the milfoil was nearly eliminated and the native macrophyte biomass grew back to 63.1 g/m^2. This is equivalent to 67,000 kg or 147,000 lbs of plant matter dry weight; wet weight would be substantially higher. Water column phosphorus levels would replenish quickly due to the low retention time in Capitol Lake, and the sediments provide a continuous source of nutrients.

Harvesting lake macrophytes would need to remove very large masses of plant material and would need to occur several times during the growing season given the speed at which native macrophytes grew back after the 2004 herbicide application. This may not be feasible as a long-term solution. In addition, harvesting can have unintended consequences such as disturbing bottom sediment communities. Reducing macrophytes in 2004 also may have contributed to the massive algae blooms that followed when the phytoplankton to longer had to compete with macrophytes for light or nutrients. This scenario was not pursued further.

Conclusions

Following publication of the technical report (Roberts et al., 2012), Ecology consulted with the Deschutes Advisory Group to identify potential management scenarios for addressing water quality impairments in the Budd Inlet, Capitol Lake, and Deschutes River watershed. The first phase of the Water Quality Improvement Report (WQIR) focuses on the Deschutes River, Percival Creek, and tributaries to Budd Inlet and sets load and wasteload allocations needed to meet water quality criteria and achieve clean water (Wagner, in press). Ecology evaluated Budd Inlet and Capitol Lake scenarios and presented them to the Deschutes Advisory Group between 2011 and 2013. The next phase of the WQIR will focus on Budd Inlet and Capitol Lake, based in part on the scenarios and findings described in this report.

The scenarios evaluated in this document were proposed as potential management actions to address dissolved oxygen (DO) problems in Capitol Lake and Budd Inlet. In addition to informing the benefits of various management actions, the scenarios reveal the complex interactions among key physical, chemical, and biological processes. Many scenarios focus on reducing human nutrient contributions to improve oxygen conditions in Capitol Lake and Budd Inlet. However, the processes interact in a way that the benefits do not necessarily scale with the nutrient load reductions, which include phosphorus for Capitol Lake and nitrogen for Budd Inlet.

Budd Inlet

Current human activities cause violations of the DO standards throughout most of Budd Inlet

The Capitol Lake dam, human nutrient sources outside of Budd Inlet, and human nutrient sources within Budd Inlet from both wastewater discharges and river inputs combine to violate the water quality standards for DO throughout most of Budd Inlet. These four human activities cause DO to decreases by as much as 3 mg/L below natural conditions. Violations occur across most of central and southern Budd Inlet and for weeks to months (Figure 8 *check*).

Roberts et al. (2012) quantified the effects of human nutrient sources on DO in Budd Inlet. However, that report included two separate baseline conditions that compared oxygen impacts from human sources to natural conditions with and without the Capitol Lake dam. Since publication, the Department of Ecology consulted with the Attorney General's office and determined that the Capitol Lake dam cannot be considered part of the natural condition. In addition, we isolated the impact of sources external to Budd Inlet using the South and Puget Sound model at the suggestion of the Deschutes Advisory Group. We learned that sources outside of Budd Inlet also cause DO impacts within Budd Inlet, in addition to the local Budd Inlet sources that were the focus of the technical report.

The natural conditions for oxygen in Budd Inlet were evaluated with the model using the following inputs:

- No Capitol Lake dam. The model grid was expanded to include the area now covered by Capitol Lake. In addition, the depths were adjusted consistent with the pseudo-equilibrium determined by USGS (George et al., 2006) under an estuary alternative. The model grid simulated the width of the opening as three grid cells, or approximately 230 ft. Budd Inlet would extend to cover the existing Capitol Lake.

- No external sources. The South and Central Puget Sound model was run with and without human nutrient sources. The differences in nitrogen, carbon, and oxygen were used to develop scalars that were then applied to estimate the influence of external sources at the northern Budd Inlet boundary. In addition, sediment fluxes were scaled down to reflect natural conditions based on ratios of nutrient sources between the current and natural condition. Therefore, natural conditions exclude the effect of external sources on northern Budd Inlet water column boundary conditions and Budd Inlet sediment fluxes.

- No Budd Inlet wastewater discharges. The flows were set to zero and no wastewater was introduced at the outfall locations under natural conditions. In addition, we scaled the sediment fluxes to reflect the decrease in external and local human loads to Budd Inlet.

- River and stream inflows to Budd Inlet at natural conditions. Natural nutrient levels were described in Appendix I of Roberts et al. (2012) for the Deschutes River and other streams flowing into Budd Inlet. In addition to reducing nutrient concentrations to the natural conditions, we also scaled the sediment fluxes to reflect the decrease in external and local human loads to Budd Inlet.

To isolate the influence of human activities, we compared minimum daily oxygen levels that would occur under natural conditions to those that currently occur throughout the model domain during January through September period. . The lowest oxygen levels or the biggest decreases from natural conditions occur in the bottom waters of Budd Inlet. Human nutrient loads stimulate primary productivity in the surface layers where light is available, which can lead to higher DO concentrations than would occur under natural conditions. However, the water quality standards do not allow water column conditions to be averaged in such a way as to mask degradation in some areas. Therefore, the model output was analyzed to focus on changes in minimum concentrations as a result of human activities. In addition, the DO standards are applied as instantaneous values, since the standards do not allow averaging over time to mask degradation.

The predicted depletion of DO at the critical location in East Bay and in most other locations is statistically significant because the predicted DO for various model scenarios are highly correlated with each other. In other words when predicted DO is low or high in one scenario it is also low or high at the same time in the natural conditions scenario or any other scenario. Practically all of the predicted DO violations for estuary alternatives are statistically significant, and most of the violations for lake alternatives are greater than the overall RMSE of 0.41 mg/L for the predicted differences.

The combined effect of the Capitol Lake dam, human sources external to Budd Inlet, local point sources, and local nonpoint sources cause most of Budd Inlet to violate the DO water quality standards (Figure 8). Compared with natural DO conditions, East Bay reflects the largest impacts from the combined effects of all human activities. This assessment includes nutrients reaching Budd Inlet from the Pacific Ocean, which is still the largest nitrogen load to Budd Inlet.

The Capitol Lake dam has the largest negative impact on DO in Budd Inlet

Overall, the Capitol Lake dam has the single largest impact on Budd Inlet DO concentrations. The negative impact results from the combined effects of circulation in southern Budd Inlet, carbon loading from Capitol Lake, and nitrogen loading from Capitol Lake. The net effect is to decrease DO concentrations by over 0.2 mg/L throughout much of Budd Inlet and as much as 2 mg/L in portions of East Bay (Figure 9).

The presence of the dam, independent of any human contribution of nutrients, increases the amount of time that water stays in Budd Inlet. The dam releases water from the Deschutes River and Percival Creek as a pulsed flow. Water stays in southern Budd Inlet longer than it would without the dam in place but with continuous inflows from the Deschutes River and Percival Creek. The increase in residence time of the water contributes to lower DO levels in southern Budd Inlet than would occur without the dam in place.

Capitol Lake receives nutrient inputs from the Deschutes River and Percival Creek. This results in extensive algae blooms in the lake. Plant growth in Capitol Lake discharges more organic carbon to Budd Inlet than would occur if the Deschutes River and Percival Creek flowed into Budd Inlet directly. Capitol Lake produces substantially more oxygen-demanding organic carbon than would occur in a natural estuary. As the excess organic carbon decays, oxygen is used up in the process. This causes lower oxygen levels than would occur without the dam in place. As described below, most of the nitrate entering Capitol Lake is released to Budd Inlet in alternative forms of nitrogen.

Local human nutrient sources cause violations of the DO standards in Budd Inlet

Local human nutrient sources from wastewater treatment plant discharges and river inflows cause oxygen levels to decrease by about 0.3 mg/L compared with natural conditions. Local sources alone cause violations of the DO standards, but also contribute to the combined effect of all human activities. The biggest impacts occur in southern Budd Inlet and East Bay in particular, where the water residence time is the largest.

We further isolated the wastewater treatment plant discharges from the human sources within river inflows. Both the wastewater treatment plant discharges and human sources within rivers contribute to 0.1 to 0.2 mg/L oxygen depletion below natural conditions. While separately they may not violate the standards, the standards are applied to the combined effect of all activities.

Among the treatment plants, we also evaluated relative impacts between the three small wastewater plants (Boston Harbor, Beverly Beach, and Tamoshan) and the LOTT discharge. The nutrient loads from the three small treatment plants (5 kg/d) represent 3% of the LOTT load (kg/d) during the April through September simulation period. Nutrient removal technology at the three small plants would not alter DO concentrations either near the discharges or in more sensitive locations in southern Budd Inlet. The LOTT discharge is the dominant wastewater source.

Human sources from external sources cause violations of the DO standards in Budd Inlet

Human nutrient sources beyond Budd Inlet cause oxygen levels to decrease by up to 0.4 mg/L compared with natural conditions. External sources alone cause violations of the DO standards and also contribute to the combined effect of all human activities. The biggest impacts occur in southern Budd Inlet, furthest from the external sources. This pattern reflects general circulation patterns. Human sources outside of Budd Inlet reach Budd Inlet as a net landward transport in the bottom waters of South Puget Sound. Coupled with the high residence time of southern Budd Inlet, these sources from beyond Budd Inlet cause oxygen depletion in southern Budd Inlet.

We evaluated this impact as a high priority for the Deschutes Advisory Group. We used the separate South and Central Puget Sound model, which is also coupled with the larger Salish Sea model, to understand how human nutrients are transported from distant sources to Budd Inlet. We then evaluated how these human sources external to Budd Inlet decreased oxygen levels below what would naturally occur. The impacts reflect the combined effect of changes in water column oxygen and nutrients as well as sediment fluxes on Budd Inlet DO.

Natural nitrogen sources from the Pacific Ocean contribute about 13,000 kg/d at the northern Budd Inlet boundary between April and September. Low oxygen would naturally occur in southern Budd Inlet. The human sources external to Budd Inlet add about 1500 kg/d at the northern Budd Inlet boundary. This load is larger than the local human sources reaching Budd Inlet, which contribute about 490 kg/d on average between April and September. Even though local human sources are close to the region of Budd Inlet most sensitive to human activities, external human sources are larger in magnitude and have a greater impact in terms of oxygen decline.

East Bay is more sensitive to human impacts than West Bay

The Capitol Lake dam, local human sources, and external human sources affect most of southern Budd Inlet but have the largest negative impact on DO in East Bay. Local human sources include wastewater discharges and the Deschutes River, but also human nutrient sources from Moxlie and Indian Creeks that discharge directly to East Bay. Human nutrients from Moxlie/Indian Creek decrease East Bay DO concentrations, but they have less of an impact than other human activities. Because the Moxlie/Indian Creek watershed is so much smaller than the lands draining through the Deschutes River and Percival Creeks, the Moxlie/Indian freshwater inputs are very small. Without large freshwater inputs, the water in East Bay stagnates and has a longer residence time than West Bay.

West Bay is not as sensitive as East Bay to human impacts, even though it receives nutrients from the Deschutes River watershed and Capitol Lake. West Bay also receives more freshwater than East Bay, which travels through West Bay very quickly, flushing this part of Budd Inlet.

The Capitol Lake dam alters circulation in southern Budd Inlet due to the pulsed outflow. The dam itself increases the residence time of East Bay. Longer residence time worsens DO concentrations compared with natural conditions. Although most of the Capitol Lake outflow is transported north along the east side of Budd Inlet, a portion of the Capitol Lake outflow reaches East Bay. Therefore, carbon and nitrogen in the water leaving Capitol Lake enter East Bay and contribute to algae growth, organic matter decomposition, and decreased oxygen concentrations than would occur without the dam in place.

Capitol Lake

Traditionally, lake management programs rely on reducing human phosphorus inputs to achieve water quality benefits in the long term. Sediments can harbor supplemental phosphorus for years to decades, depending on the lake geometry, and these sediment releases can support overabundant plant growth even after human sources are reduced. Sometimes short-term actions are recommended as well.

For Capitol Lake, watershed management programs would not improve water quality in the lake due to the physical shape of the lake and relative size of the Deschutes River watershed. Even if all human sources were controlled, natural phosphorus concentrations from the large Deschutes River and local watershed would deliver ample nutrients to support luxuriant suspended plant growth in the shallow waters of Capitol Lake. Even at natural loads per unit lake surface area (fertilization rate), Vollenweider (1968) indicates that Capitol Lake would remain a eutrophic system. Stringent nutrient-control programs would not visually or measurably improve Capitol Lake water quality.

Watershed controls are still important to support healthy functions in the riverine environments. For example, nutrient controls and restored riparian vegetation are needed to benefit the Deschutes River and Percival Creek. These should happen even though they would not benefit Capitol Lake itself. However, Capitol Lake’s poor water quality will continue due to the large watershed tributary to the small, shallow lake.

Capitol Lake transforms nitrogen from inorganic to organic forms

Capitol Lake receives nitrogen, generally in the form of nitrate, from the Deschutes River and Percival Creek. The computer model of Capitol Lake correctly predicts that the water leaving Capitol Lake has lower nitrate concentrations than the water entering through the Deschutes River during the growing season. Monitoring data confirm that nitrate concentrations exiting the lake are lower than those entering the lake during the summer season. Phytoplankton and macrophytes within the lake transform nitrogen from nitrate to organic nitrogen forms. As the plants die and decay, the nitrogen is released back to the water column where it can reach Budd Inlet. A portion of the nitrogen is cycled within the sediments and some is buried. Capitol Lake decreases nitrate and total nitrogen seasonally, although the majority of this nitrogen still reaches Budd Inlet.

Dredging Capitol Lake would not improve water quality

Since the trophic state is also related to the average lake depth, deepening the lake theoretically could help. However, dredging to a nominal 13 ft depth would still result in highly eutrophic conditions. Even if all human sources within the Deschutes River watershed were controlled, natural sources alone would maintain eutrophic conditions. Further, even if both human and natural sources were eliminated, the sediments would naturally contribute enough phosphorus to maintain eutrophic conditions.

Dredging to 13 ft would not decrease light availability to bottom-rooted plants, and macrophytes would continue to grow. The dredged depth would need to be deeper to reduce light availability to macrophytes. Even if this were accomplished, the lake would need to be dredged to 100 m to shift from eutrophic to mesotrophic conditions, and a decrease in overall plant growth. However, sediments would not maintain steep side slopes after dredging and would shift to follow the natural angle of repose. This would create broad margins where macrophytes could grow even if the lake were deeper than typical euphotic zones (roughly 15 ft).

Deschutes River watershed improvements would not clean up Capitol Lake

Watershed improvements, such as increasing riparian shade along the Deschutes River, controlling human sources of sediments, and reducing human nutrient sources, would not improve conditions within Capitol Lake.

Improving riparian shade would decrease peak Deschutes River waters temperatures, a significant benefit to the biota in the Deschutes River. Waters with cooler temperatures hold more oxygen, and improving riparian shade would also improve Deschutes River oxygen conditions. However, these effects would not benefit Capitol Lake. The temperature of the lake is strongly controlled by the solar radiation reaching the surface of the lake. Cooler temperatures, with corollary oxygen saturation benefits, would occur in only a small portion of South Basin. Once the river water flows under the I-5 bridge, the water slows such that the temperature of the inflow equilibrates with the heat flux driven by solar radiation and other surface heat exchanges between the air and the water. This is why temperature improvements due to riparian vegetation restoration along the Deschutes River do not translate to oxygen benefits in Capitol Lake.

Controlling human sources of fine sediments would improve habitat conditions in Deschutes River spawning gravels. However, natural sources such as landslides produce most of the fine and coarse sediments. Therefore, even after human sources are controlled, natural sources will continue to travel downstream in the Deschutes River watershed. With the Capitol Lake dam in place, most of these natural sediments would continue to decrease the depth and volume of the lake, maintaining eutrophic conditions within the lake.

Deschutes River nutrient concentrations are higher than would naturally occur. Reductions in human nutrient sources are needed to improve DO and pH in the Deschutes River. Eliminating all human phosphorus sources would decrease the loading to Capitol Lake, but the loading would still maintain eutrophic conditions in Capitol Lake. The phosphorus loading would need to be reduced by 99.9% to shift the lake to mesotrophic conditions and decreased plant growth. This is not feasible due to the natural sources of phosphorus in the Deschutes River watershed.

Decreasing phosphorus and sediments reaching Capitol Lake from urban stormwater runoff is needed to control controllable sources as stipulated in municipal stormwater permits. While this management action is needed for multiple reasons, even controlling all urban stormwater sources to Capitol Lake, alone or in concert with decreasing Deschutes River phosphorus loads, would not decrease the phosphorus load enough to shift from eutrophic conditions.

Watershed cleanup is needed to address conditions within the watershed and to meet stormwater permit requirements. These should occur regardless of the benefit to Capitol Lake. However, we evaluated these scenarios to check for any subsequent benefits to Capitol Lake. Watershed improvements, as individual or collective actions, would not improve conditions in Capitol Lake. Capitol Lake would remain eutrophic with excessive plant growth due to the shallow water depths and natural nutrient sources in the watershed and sediments.

Alum treatment

While clearing the water column with an alum treatment reduces the phosphorus available to drive algae growth, the rooted macrophytes would still grow because of natural and human phosphorus sources in the sediments. Further, the Deschutes River would continue to bring natural and human phosphorus sources. Harvesting lake plants would require tons of material removed to keep up with natural inputs from the Deschutes River each year. This is unlikely to deplete sediment phosphorus sources.

Recommendations

Based on the analyses conducted in 2011-13 we recommend several actions and next steps.

Conduct Additional Analyses to Refine the Estimates of External Sources on Budd Inlet

We evaluated the potential impacts from sources beyond Budd Inlet on Budd Inlet water quality using the separate model of South and Central Puget Sound (Roberts et al., 2014a). These scenarios also considered the influences on sediment fluxes and boundary conditions for nutrients and oxygen that would accompany any changes to external loading. While this is the best available information using the tools and data now, Ecology is pursuing the development of a more detailed model application for the Salish Sea that calculates the changes in sediment fluxes that would result from changes in external loading and primary productivity (Roberts et al., 2014b).

We recommend that the results of the Salish Sea modeling inform the South and Central Puget Sound model, and that the South and Central Puget Sound model be used to inform Budd Inlet boundary conditions for alternative loading analyses. The results will be used to refine the estimates of impacts from sources outside of Budd Inlet, an important step needed to allocate a maximum 0.2 mg/L impact to the four sources currently impacting Budd Inlet: Capitol Lake dam, external sources, local point source, and local river sources. Until the magnitude of the external source impacts is refined, we do not know how much various sources would need to be reduced to meet water quality standards.

In addition, the refined Salish Sea and South and Central Puget Sound modeling tools could be used to evaluate the impacts of individual sources. The present scenarios are based on the combined effects of existing marine point sources and human sources within rivers throughout South and Central Puget Sound. However, refined modeling tools could determine which of the sources or combination of sources are affecting Budd Inlet dissolved oxygen (DO) levels.

Develop Scenarios That Combine Potential Management Actions

Most of the scenarios presented in this report isolate the influence of an individual human activity on Budd Inlet DO. No single scenario eliminating a single source produced DO concentrations that meet water quality standards. Therefore, future management activities must include a combination of management actions to successfully meet standards.

A few scenarios evaluated multiple actions. However, the combined effect of eliminating LOTT discharges between March and September; decreasing nonpoint sources by 50%; and eliminating the Capitol Lake dam still would not meet the water quality standards.

Additional scenarios should be evaluated that add in the effect of reducing external sources in addition to controlling local sources and eliminating the impacts from Capitol Lake.

Next Steps

The next steps include the following:

- Continue the development of the first phase of the Water Quality Implementation Report (WQIR) for the Deschutes River, Percival Creek, and tributaries to Budd Inlet. Management actions targeting fecal coliform bacteria, fine sediment, and temperature will also benefit dissolved oxygen Budd Inlet and Capitol Lake.

- Continue evaluating potential management scenarios and discuss with the Deschutes Advisory Group.

- Complete the second phase of the WQIR for Budd Inlet and Capitol Lake.

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Appendices

Appendix A. Summary of Methods of Estimating Scalars for Sediment Fluxes and Open Boundary Water Quality Variables

Scalars for natural conditions

The scalar multipliers for adjustment of the open boundary concentrations and sediment fluxes were estimated by a nested modeling approach using two other larger-scale models:

- The South Puget Sound Dissolved Oxygen Study (SPSDOS) model includes Budd Inlet in addition to the entire south and central Puget Sound regions south of Edmonds, WA (Ahmed et al., 2014).
- The Salish Sea model includes the entire Salish Sea (Roberts et al., 2014)

The nested models were used in the following stepwise sequence to estimate scalars that were used to adjust the existing open boundary concentrations and sediment fluxes to reflect the natural conditions (the scalar is the ratio of natural vs existing conditions to be multiplied by the existing condition to estimate the natural condition):

1. Estimate the natural conditions scalar to adjust the sediment fluxes in the Salish Sea model within a super-region defined by Point-No-Point, Deception Pass, and Swinomish Channel (**Error! Reference source not found.**) using an iterative solution with the Salish Sea model based on matching the assumed ratio of natural/existing sediment/water fluxes with the model-predicted ratio of natural/existing April-September particulate N deposition fluxes into the sediment.
2. Estimate the natural conditions scalar to adjust the open boundary in the SPSDOS model using the results of the Salish Sea model evaluated across a transect near Edmonds using the ratio of predicted incoming April-September time-weighted average water column concentrations for natural vs existing conditions.
3. Estimate the natural conditions scalar to adjust the sediment fluxes in the SPSDOS model using an iterative solution with the SPSDOS model based on matching the assumed ratio of natural/existing sediment/water fluxes with the model-predicted ratio of natural/existing April-September particulate N deposition fluxes into the sediment.
4. Estimate the natural conditions scalar to adjust the open boundary in the Budd Inlet model using the results of the SPSDOS model evaluated across a transect at the entrance to Budd Inlet using the ratio of predicted incoming April-September time-weighted average water column concentrations for natural vs existing conditions.
5. Estimate the natural conditions scalar to adjust the sediment fluxes in the Budd Inlet model using an iterative solution with the Budd Inlet model based on matching the assumed ratio of natural/existing sediment/water fluxes with the model-predicted ratio of natural/existing April-September particulate N deposition fluxes into the sediment.

Estimated reflux of local anthropogenic sources

Reflux is defined as the fraction of the loading into Budd Inlet that returns back into Budd Inlet after it leaves across the open boundary. The reflux fraction was estimated using the SPSDOS model by comparing two scenarios: 1) natural conditions, and 2) natural conditions plus existing (2007) loading from LOTT. The difference between incoming total N loads across the open boundary for these two scenarios was assumed to represent the amount of total N load from LOTT that was refluxed back into Budd Inlet across the open boundary. The ratio of the refluxed load to the total load from LOTT was assumed to represent the refluxed fraction of loading. The reflux fraction was found to be approximately 20% (i.e. about 20% of the load from LOTT re-enters Budd Inlet back across the open boundary after it leaves Budd Inlet).

Scalars for various management scenarios

We estimated the scalars for open boundary concentrations and sediment/water fluxes for each management scenario by linear interpolation between the estimated scalars for natural and existing conditions. The interpolation between existing and natural scalars was based on the following:

- For sediment scalars the interpolation was based on the April-September incoming total N load from local sources (point sources, natural and anthropogenic nonpoint sources, and atmospheric deposition) plus incoming total N loads across the open boundary (sum of natural, external anthropogenic, and refluxed internal anthropogenic).
- For water column scalars the interpolation was based on the April-September incoming total N loads across the open boundary (sum of natural, external anthropogenic, and refluxed internal anthropogenic).

Incoming total N loads across the open boundary were estimated as the sum of natural sources, external anthropogenic sources, and refluxed internal anthropogenic sources. External anthropogenic sources were estimated based on the difference between existing and natural total N load across the open boundary minus the refluxed fraction of local WWTP and river loads under the existing condition. Natural loading across the open boundary was estimated from the natural conditions scenario of the SPSDOS model. Refluxed internal anthropogenic loading was estimated based on the reflux fraction applied to the sum of WWTP and river discharges into Budd Inlet.

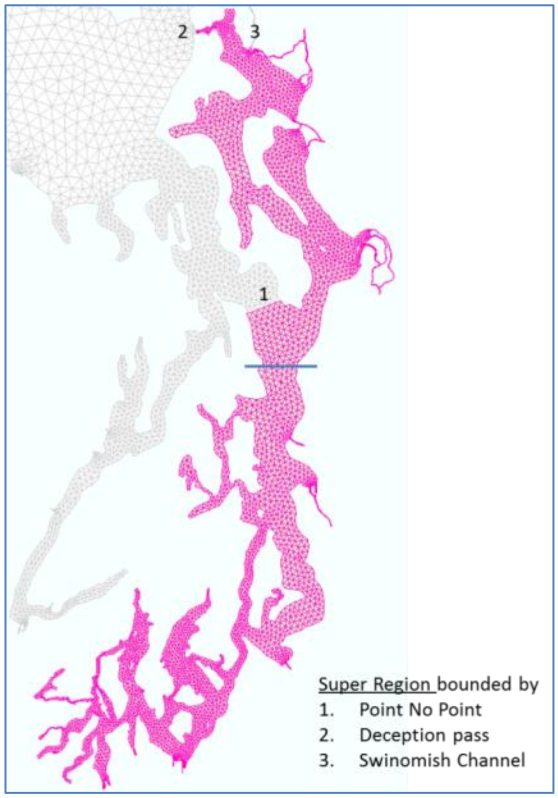

Figure A-1. Salish Sea model super-region.

Appendix B. Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Diel: Of, or pertaining to, a 24-hour period.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Riparian: Relating to the banks along a natural course of water.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

(Author **delete** all acronyms and abbreviations that don't apply)

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

BMP	Best management practice
DO	(See Glossary above)
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
MEL	Manchester Environmental Laboratory
NPDES	(See Glossary above)
NTR	National Toxics Rule

PBDE	polybrominated diphenyl ethers
PBT	persistent, bioaccumulative, and toxic substance
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
SRM	Standard reference materials
TMDL	(See Glossary above)
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WQIR	Water Quality Implementation Report
WRIA	Water Resource Inventory Area
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cms	cubic meters per second, a unit of flow
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
l/s	liters per second (0.03531 cubic foot per second)
m	meter
mg	milligram
mgd	million gallons per day
mg/d	milligrams per day
mg/L	milligrams per liter (parts per million)
mL	milliliters
mm	millimeters
mmol	millimole or one-thousandth of a mole
mole	an International System of Units (IS) unit of matter
psu	practical salinity units
s.u.	standard units
ug/L	micrograms per liter (parts per billion)
uM	micromolar, a chemistry unit